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PLASTIC PIPE IN AIRPORT DRAINAGE SYSTEMS.(U)

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PLASTIC PIPE IN AIRPORT DRAINAGE SYSTEMS

Gary G. Harvey

U. S. Army Engineer Waterways Experiment Station
Soils and Pavements Laboratory
P. O. Box 631, Vicksburg, Miss. 39180

JANUARY 1977
INTERIM REPORT

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16. Abstract

This interim report provides tentative selection, design, installation, and maintenance guidelines for the use of three material types of plastic pipe components in airport drainage systems. The three types chosen for recommended use are: (a) polyethylene (PE); (b) polyvinyl chloride (PVC); and (c) acrylonitrile-butadiene-styrene (ABS). The specific plastic pipe products of these three materials that are dealt with in detail in this report are perforated corrugated PE tubing and perforated smooth-wall PVC pipe for underdrains; and unperforated smooth-wall PVC and ABS composite pipe for storm drains, collector drains, and small culverts.

Available plastic pipe products were evaluated for their potential performance in airport drainage applications. The evaluation considered such factors as pipe strength, soil-structure interaction, chemical and ultraviolet radiation resistance, abrasion resistance, and resistance to biological attack.

Known advantages, limitations, and risks are presented for each of the systems chosen for detailed consideration. The recommended guidelines contained herein result from an extensive literature survey, several on-site inspections, and personal contacts with researchers, owner/user/operators, designers, consultants, and constructors. All are tentative in nature; validation/verification testing will be conducted during the continuation of this project.

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PREFACE

The study described in this interim report was conducted at the U. S. Army Engineer Waterways Experiment Station (WES) under the sponsorship of the Federal Aviation Administration (FAA), Inter-Agency Agreement No. DOT FA75WAI-536. Phase I of this study has been completed and FAA Report No. FAA-RD-76-59 entitled "Improvements to Airport Drainage Criteria, Phase I," October 1976, has been published.

Phase II of this study was conducted and the interim report prepared during the period May 1976-September 1976 by Mr. G. G. Harvey under the supervision of Mr. H. H. Ulery, Jr., Chief of the Pavement Design Division, and Messrs. J. P. Sale and R. G. Ahlvin, Chief and Assistant Chief of the Soils and Pavements Laboratory, respectively.

Directors of WES during conduct of the study were COL G. H. Hilt, CE, and COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

METRIC CONVERSION FACTORS

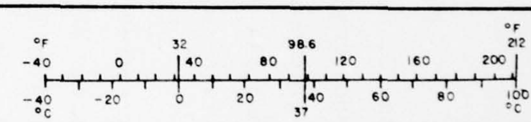
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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PLASTIC PIPE IN AIRPORT DRAINAGE SYSTEMS

INTRODUCTION

BACKGROUND

In recent years a number of plastic pipe* products have become available to the transportation industry which appear to have good potential for economical and successful use as underdrains, storm sewers, culverts, and other drainage structures. However, plastic pipe products have not been used extensively primarily because of the lack of experience industry-wide. Transportation planners and designers have been reluctant to use plastic pipe products as alternates to the more conventional pipe products whose in-service behavior is well established by long years of experience in many applications. Another reason for the reluctance to use plastic pipe is the lack of standardized design, construction, and maintenance guidelines. This is true throughout the transportation industry, but is especially lacking for application of plastic pipe in airport drainage systems. Accordingly, an appraisal of the theoretical considerations and field performance of buried plastic pipe is required to determine how it can best be used in such systems. After this appraisal is sufficiently complete, a set of standards and/or guidelines for selection, design, construction, and operation and maintenance of plastic pipe for airport drainage systems can be developed.

OBJECTIVE

The overall objective of this report is to present a set of tentatively recommended technical requirements and guidelines that are based on a synthesis of information drawn from an extensive literature review, several site inspections, and many personal contacts with knowledgeable people in the drainage and plastics industries. The report provides

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* Note that throughout this report the words "plastic pipe" are to be interpreted as meaning "thermoplastic pipe" as distinguished from "thermosetting pipe."

techniques and guidelines which will either be verified or invalidated by testing that will be carried out in a future extension of Phase II of this project.[1]

SCOPE

An extensive literature search and state-of-the-art evaluation were conducted to obtain technical information concerning plastic pipe, soil-structure interaction, design and construction techniques, and performance of plastic pipe used in drainage systems. (The interim report[2] by Chambers and Heger was found to be particularly useful as a source of information.) Many personal interviews and discussions were also held concerning design and construction experience and plastic pipe performance. The scope of this report is limited to the use of plastic pipe for storm sewers, collector drains, and subdrains; therefore, application of plastic pipe products in pressure systems is excluded. This report endeavors only to present reasonable and plausible design, construction, and maintenance techniques and guidelines concerning the use of plastic pipe in airport drainage systems which can be used as presented, used after modification, or discarded depending upon the results of the planned test and evaluation program to be conducted henceforth.[1]

RESULTS OF RESEARCH

LITERATURE SEARCH/STUDY

GOALS

Available literature, including articles in various periodicals, was surveyed with the following goals in mind:

<u>a</u>. Identify and evaluate available plastic pipe products for potential performance in drainage applications, considering pipe strength, soil-structure interaction, chemical and abrasion resistance, biological attack susceptibility, etc.

<u>b</u>. Compare advantages, limitations, and risks of the various plastic pipe products when used in drainage systems.

<u>c</u>. Identify design, selection, and installation techniques and guidelines and determine their applicability, and reliability.

<u>d</u>. Establish, as nearly as possible, a performance record of plastic pipe products in various applications.

AVAILABLE PLASTIC PIPE

Plastic pipe currently available for airport drainage systems and considered appropriate for consideration in later stages of the Phase II research effort are discussed below.

<u>Polyvinyl chloride (PVC).</u> PVC sewer pipe has been used primarily in sanitary sewers, but has also been used in storm sewers. The maximum standard diameter currently available is 15 in.; however, an increase to 24 in. is expected.[2] Perforated PVC pipe has also been used extensively for leaching fields and in agricultural drainage systems. PVC pipe can compete favorably with conventional sewer pipe systems on an installed cost basis, primarily because it is lightweight, easily handled, and installed in long lengths. Resistance to chemical attack and lack of brittleness are cited by many users and consultants as major factors in the generally satisfactory performance of PVC. PVC is, however, susceptible to chemical alteration and deterioration when exposed to direct sunlight.

<u>Acrylonitrile-Butadiene-Styrene (ABS).</u> ABS pipe comes in two basic forms: solid-walled and composite. ABS composite pipe is a

double-wall pipe consisting of two thin concentric annular shells (walls) interconnected with continuous diagonal plastic web elements forming a circular "truss" cross section. The void between the walls and the webs is filled with a foamed cement. The solid-wall ABS comes in smaller diameters only (≤6 in.). It has been used most in sanitary sewers and some pressure systems. The ABS composite (trussed-wall) pipe is used principally in sanitary sewers, with some application in storm sewers. At this time 15 in. is the maximum standard diameter. ABS composite pipe is the most widely used plastic pipe for diameters larger than 8 in. It competes very well with conventional sewer pipe systems and with PVC pipe on the basis of installed cost. Owners and consultants almost unanimously report satisfactory performance; and in many cases the ABS composite pipe has performed better than pipe of conventional materials. Although ABS has a generally excellent performance record, it does have certain disadvantages. It is susceptible to attack by more chemicals than PVC, including gasoline, and is very susceptible to direct sunlight (ultraviolet radiation).

Corrugated polyethylene (PE) tubing. Perforated corrugated PE drainage tubing has been used most extensively for agricultural land drainage and for sewage leaching beds. There has been limited use of PE tubing in highway underdrainage, and the potential cost savings make its use attractive to several state highway departments. It should also have good applicability in airport underdrain systems. Corrugated PE tubing is available in diameters up to 18 in. for underdrain application, but the maximum diameter covered by the American Society for Testing and Materials (ASTM) Specifications is 8 in. To permit more wide usage in airport underdrainage significant product design development needs to be done and new ASTM material and installation standards need to be developed and published. PE solid-wall pressure and forced main sewer pipe have some potential for use as storm sewer mains and culverts. The applicable experience record is mostly in Europe; experience in the U. S. is principally as sewer or culvert relining, forced pressure mains, and outfalls. Solid-wall PE pipe is available in sizes up to 48 in., but

the product is not covered by ASTM specifications. Although PE solid-wall pipe is perhaps too expensive for most potential drainage applications, it may be highly appropriate in special cases.

USAGE AND PERFORMANCE RECORD OF PLASTIC PIPE (NONPRESSURE)

Plastic piping and/or tubing products have been manufactured and available for various uses for about 15 to 20 years, but substantial usage has occurred only in the last 8 to 10 years. Much of the existing performance record concerns pressure piping; however, there exists a significant performance record for nonpressure applications of plastic pipe.

The two types of systems in which the great majority of plastic pipe has been used are sanitary (and some storm) sewers (unperforated) and agricultural land drainage and sewage leaching beds (perforated). Pipe and tubing have been manufactured of many different plastic materials, including PVC, ABS, PE, Styrene-Rubber (SR), Fiberglass Reinforced Plastic (FRP), and Reinforced Plastic Mortar (RPM). There are also two primary structural configurations: smooth-walled and corrugated. The types and configurations of the plastic pipe most used and for which the longest and most complete service or performance records exist are the following:

a. Solid- and smooth-walled PVC, and ABS composite pipe in sanitary and storm sewers.

b. Perforated smooth-walled PVC and corrugated PE pipe or tubing for agricultural land drainage and sewage leaching beds.

Performance data and use records for the other plastic pipe products listed before are either extremely lacking or most reported experience with a given product has been unfavorable. Most past single-project installations were a mile or less in length; but the number of longer installations has been increasing in recent years.

DESIGN AND CONSTRUCTION PROCEDURES

Published design and construction information for plastic pipe systems is in many forms. Magazine articles, technical society journals,

research reports from consultants and research organizations of various types, technical reports from industry product promotional institutes, and manufacturer's publications are all good sources of information. Also, for the designer and constructor of plastic pipe systems, there are some standards, specifications, and guide specifications available. Virtually all published information about plastic pipe systems has been published within the last 10 to 15 years.

As much of the reviewed published information as possible was incorporated into the tentative technical recommendations section of this report. A comprehensive listing of the reviewed literature is contained in the Bibliography.

INSPECTIONS AND PERSONAL INTERVIEWS

INSPECTION OF PLASTIC PIPE INSTALLATIONS

To obtain first-hand, on-site knowledge of the use of plastic piping systems, inspection trips were made to three installations. Two of the three involved the use of ABS composite and solid-wall PVC sewer pipe in municipal sanitary sewer systems. The other was to an Air Force Base at which perforated PVC pipe has been used as underdrains under an aircraft parking apron and its contiguous taxiway. All installations inspected were in excellent working order. Although the underdrain has only been in use for about 3 years, its performance has been good and no major problems are expected in the future. The two municipalities first installed ABS composite and PVC sewer pipe between 1969 and 1971. Both have continued to expand their sewer systems, still using plastic pipe. Colorado Springs, Colorado, was installing some more 15-in. ABS composite sewer pipe at the time of the author's inspection.

Further details of these inspections are contained in the two trip reports in Appendix B of this report.

Most of the very few reported failures of plastic pipe or fittings have been attributable to faulty installation. Plastic pipe products most used have inherent characteristics that allow the pipe system to be more "forgiving" of construction shortcomings or deficiencies.

Several agencies in the United States have performed (or are performing) tests on various plastic pipe materials and products. Among these are: Bureau of Reclamation (BuRec) (see Bibliography, Howard, A. K. et al., 15 references); Engineering Experiment Station, Utah State University (see Bibliography, Watkins, R. K. et al., 10 references); California Department of Transportation;[2] New York State Thruway Authority;[2] Illinois Department of Transportation;[2] and the Georgia Department of Transportation.[2]

There has been virtually no usage of plastic pipe in airport drainage systems. In the extremely few instances that plastic pipe has been used, the application has been underdrains and collector drains along and under taxiways, runways, and aprons (see INSPECTIONS AND PERSONAL INTERVIEWS).

As with any unproven product, the use of plastic pipe involves application risks. The principal risks (which have been mainly identified by actual use of plastic pipe) involved are mostly related to exposure to problem chemical agents, fire, possible attack by rodents (most concern is with PE tubing), and poor or improper installation. Additional risks in using ABS composite pipe compared to PE and PVC pipe include a greater sensitivity to a larger number of chemicals and the absence of a rational method of evaluating short-term or long-term structural performance.

Important advantages cited by users for the use of plastic piping in drainage of transportation facilities include lower installation cost, much improved resistance to aggressive soils and most deicing compounds (especially salt), and reduced cleaning and other maintenance costs compared to conventional systems.

PERSONAL INTERVIEWS

Many personal contacts were made by the author while on the trips reported in Appendix B. The people interviewed were user/operators, designers, specifiers, constructors, consultants, and researchers. Other contacts were made exclusive of the trips; these provided additional performance testimonials and technical information. One of the performance

testimonials came from the city of Greensboro, North Carolina, where a large majority of the municipal sewer system is composed of plastic pipe. Significant usage of plastic pipe began in 1971-1972, but the city is so well satisfied with the performance and cost benefits that the plastic pipe systems are preferred to any conventional system.

TENTATIVE TECHNICAL RECOMMENDATIONS

PIPE MATERIALS - PROPERTIES AND CHARACTERISTICS

GENERAL

Although there are many candidate plastic pipe materials to choose from, only a limited number meet the following "selection considerations:"

- a. Good experience record in substantial drainage-related applications (e.g., sanitary sewers, storm sewers, agricultural land drainage, foundation drains) in the United States.
- b. Availability of ASTM standards covering the basic product.
- c. Some degree of computational verification of short- and long-term structural performance at selected buried depths (except for ABS composite pipe), with consideration of other available performance factors.
- d. Limitation of pipe diameters to 18-in. or less to minimize risks associated with structural requirements of larger sized pipe. (This proves restrictive in the case of culvert applications.)

The plastic pipe systems which most nearly meet this set of selection considerations; and, therefore, the ones chosen for detailed consideration in this report and to be primarily considered in the verification testing phase of this project are:

- a. Corrugated perforated PE tubing and perforated PVC sewer pipe for underdrains.
- b. PVC and composite ABS sewer pipe for storm drains and small culverts.

Perforated PVC pipe and ABS composite pipe do not meet all of the above criteria, but have been selected because of the satisfactory performance of each basic system in sanitary sewer applications. Cost was not a criterion for selection, although these primary systems have evolved into use on the basis of economy over other plastic pipe systems and over many competitive conventional systems.

Piping systems which should be considered secondarily in future study are: perforated single-wall ABS pipe for underdrains; ABS, PE,

and Reinforced Plastic Mortar (RPM) solid-wall pipe for storm drains and culverts; and corrugated PE tubing for secondary culverts. These pipes are not included as primary candidates because the experience record is very limited, in some cases ASTM specifications and/or standards are not available, and in the case of RPM, past performance has been mixed. These are not considered in any detail in this interim report.

The following sections describe the materials properties and characteristics for each of the primary and secondary plastic pipe systems.

POLYVINYL CHLORIDE (PVC)

<u>General.</u> PVC pipe for storm sewer and underdrain applications is supplied in diameters from 4 to 15 in., and sizes up to 24 in. are anticipated in the near future.[2] Pipe is usually supplied in laying lengths of 12.5 and 20 ft. Table 1 summarizes the key characteristics and available information on PVC sewer and underdrain pipe. This table does not constitute a specification; it merely gives nominal values and properties that can be generally attributed to PVC pipe.

<u>Product specifications.</u> The basic specifications that have been generally adopted are: ASTM D 3033, "Standard Specification for Type PSP Poly (Vinyl Chloride) (PVC) Sewer Pipe and Fittings;" and ASTM D 3034, "Standard Specification for Type PSM Poly (Vinyl Chloride) (PVC) Sewer Pipe and Fittings" (see Appendix A for listing of other applicable ASTM standards). The two specifications are essentially identical, except for wall thickness, related pipe stiffness, and diameter range. Wall thickness when dealing with plastic pipe has been specified as the standard dimension ratio (SDR)*. Table 1 exhibits these differences. The dual specifications for PVC sewer pipe can be confusing to the user, and probably should be combined into one.

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* SDR is used in this interim report because it is the nomenclature of 1975 ASTM standards. ASTM F 412-75 indicates that pipe now designated SDR 35 and 42 do not have "standard" dimension ratios. It is expected that these pipes will be designated as DR ("dimension ratio") in the future.

Table 1. PVC Sewer Pipe for Storm Sewers and Underdrains*
(This is not a Specification)

SECTION PROPERTIES (nominal)

Property	ASTM	SDR	Diameter (nom.) in. 4	6	8	10	12	15
	D3033	41	0.125*	0.153	0.199	0.249	0.299	0.375
Wall thickness (in.)	D3034	42	-	-	0.200	0.250	0.300	-
		35	0.125*	0.180	0.240	0.300	0.360	-
	D3033	41	1.1	1.9	3.5	5.3	7.3	11.3
Weight (lbs/ft)	D3034	42	-	-	3.5	5.3	7.3	-
		35	1.1	2.2	4.2	6.4	8.9	-
	D3033	41	51	28	28	28	28	28
Pipe Stiffness (psi)	D3034	42	51	28	28	28	28	28
		35	51	46	46	46	46	46

* 4 in. pipe, with a 1/8 in. minimum wall has an SDR of 33.5

MATERIAL PROPERTIES (nominal)

Specific gravity (g/cm^3)	1.4
Modulus of elasticity at 73F (psi)	
Short term (minutes)	400,000
Long term (11 years)	260,000
Tensile strength at 73F (psi)	
Short term (minutes)	7,000
Long term (11 years)	4,000
Fatigue endurance limit	1,500
Brittleness temperature	unknown
Coefficient of expansion (in./in./°F)	30×10^{-6}
Fire properties	burns (self-extinguishing)

HYDRAULIC PROPERTIES

Hydraulic coefficient-Manning (n)	0.010-0.013
Perforations (see Product Specification)	varies

BURIAL (Margin of Safety)

Fair quality embedment (M_s=500 psi)	
10 ft burial	2
2 ft burial under H20 wheel load (cyclic)	1+
High quality embedment (M_s=5000 psi)	
10 ft burial	9
2 ft burial under H20 wheel load (cyclic)	5
Minimum cover during construction (ft)	2.0

USE CRITERIA

Rodent attack	possible
Microbiological attack	nil
Insect attack	unlikely
Installation temperature - at surface of pipe	
Minimum (F)	unknown
Maximum (F)	unknown
Effects of freezing and thawing (durability)	nil
Abrasion resistance (scouring flow rate maximum)	
2 FPS	unknown
10 FPS	unknown
20 FPS	unknown
Cleanout	water jet

CHEMICAL RESISTANCE

Run-off	o.k.
Soil	o.k.
Problem contaminants	ketones, esters, aromatic hydrocarbons, some oils

FITTINGS AND CONNECTIONS

Tees	available
Wyes	available
Elbows	available
Basic connection mode	bell and spigot
storm sewers	gaskets
underdrains	slip fit

* From Reference 2

The basic specifications cover PVC pipe in the diameter range shown in Table 1 as well as a wide variety of fittings. The scope of the specifications includes requirements and methods of test for materials, dimensions, workmanship, pipe flattening resistance, impact resistance, pipe stiffness, extrusion quality, joining methods, and marking.

Recommended modifications of ASTM D 3033 and ASTM D 3034. Since the two specifications are essentially identical, the changes and amendments proposed hereafter apply to both unless otherwise noted. Most of these proposed changes have been adopted from the Interim Report for National Cooperative Highway Research Program (NCHRP) Project 4-11.[2]

a. In Section 5.1 of the specifications delete all reference to type 13364-B and type 13343-C materials. Long-term strength properties of these materials have not been established. Also, to ensure that the resin grade of the Basic Specifications has the capability of providing an established level of long-term strength, add the following sentence to the end of the paragraph: "Compounds made from the two resins listed above shall be of a quality capable of providing a hydrostatic design basis (HDB) of 4,000 psi for water at 23° C (73.4° F), i.e., PVC 1220."

b. In Section 6.1, Solvent Cement Joints, add to first paragraph: "Solvent cement joints are not recommended for pipe larger than 4 in. in diameter." Solvent cement joints of PVC are difficult to fabricate reliably in diameters larger than 4 in. Therefore, they are not appropriate for use with the sizes normally used in storm drainage. Perforated underdrains are usually dry slip-fitted.

c. In Section 7 add a new paragraph as follows:

"7.11 Minimum Hydrostatic Burst Pressure--When tested at 23° C (73.4° F) in accordance with 8.11 the minimum burst pressure of pipe shall be 2.41 MPa (350 psi) for SDR 41 and 42 pipe and 2.90 MPa (420 psi) for SDR 35 and 4-in. pipe. The minimum burst pressure of fittings shall be 1.38 MPa (200 psi)."

Also add a new note as follows:

"Note 5--the minimum burst pressure for fittings is lower than those for pipe because the geometry, particularly area and radii, is such that the stresses produced in the walls of the fittings are higher than those in the pipe when tested at the same internal pressures. This requirement is intended only for the purpose of quality control to ensure that the pipe and fittings have no weak areas. It is not intended for use as a simulated-service test."

The new note gives reasons for the added requirement. The requirement is similar to that of ASTM D 2661 and ASTM D 3311 (see Appendix A), which covers nonpressure; nonstructural; drain, waste, and vent (DWV) pipe.

To this same Section 7 also add the following paragraphs:

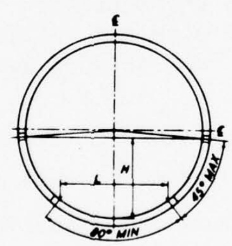
7.12 Perforated Pipe--Perforated PVC pipe shall have the following characteristics:

7.12.1 The perforations shall be circular and cleanly cut (i.e., no residual ridges, barbs, or other rough edges); shall have nominal diameters of not less than 4.8 mm (3/16 in.) nor greater than 9.5 mm (3/8 in.); and shall be arranged in rows parallel to the axis of the pipe. The rows of perforations shall be arranged in two equal groups placed symmetrically on either side of a lower unperforated segment, corresponding to the flow line of the pipe. The annular spacing of the rows shall be uniform, but the center-to-center spacing of the rows shall not be less than 25.4 mm (1 in.). The minimum number of longitudinal rows of perforations, the maximum heights of the center lines of the uppermost rows above the invert, and the inside surface chord lengths of the unperforated segment shall be as specified in Table 12.

7.12.2 Beam strength of perforated pipe shall be no less than 95 percent of that for nonperforated pipe when tested in accordance with Paragraphs 37 to 39 of ASTM D 2314."

The following table is Table 12 to be added:

Table 12. Requirements for Perforations



Diam of Pipe, Inches (mm)	Min Rows of Perforations	H Inches (mm)	L Inches (mm)
4 (102)	2	1-13/16 (46)	2-9/16 (58)
6 (152)	4	2-3/4 (70)	3-7/8 (88)
8 (203)	4	3-11/16 (94)	5-1/8 (130)
10 (254)	4	4-9/16 (116)	6-7/16 (164)
12 (305)	6	5-1/2 (140)	7-11/16 (195)

The perforation design has been taken from the American Association of State Highway and Transportation Officials (AASHTO) Specification M-175 for Perforated Concrete Pipe. The beam strength requirement ensures that longitudinal bending strength is not impaired by the perforations.

d. Section 8.8 in ASTM D 3033-76 has a typographical error in the third sentence. The sentence should refer to "Table 11" and not "Table 6."

Add a new paragraph as follows:

"8.11 Minimum Hydrostatic Burst Pressure--The test procedure and equipment shall be as specified in Method D 1599. The specimens shall be selected at random. Three specimens of pipe, each ten times the nominal diameter, or a maximum of 914 mm (3 ft), in length, shall be tested. Also, test three complete fittings. Test the specimens individually with water under pressure that is increased uniformly to cause the specimen to burst within 60 to 70 s. Fit one end of the pipe or fitting rigidly to the pressurizing apparatus, leaving the other end free but supported if necessary. All air must be removed from the pipe or fitting before sealing and testing. Any suitable closure (cap) that is free of leaks at maximum pressure may be used. Condition the specimens in water for at least 2 hr at 23 ± 1.7° C (73.4 ± 3.0° F). Examine each specimen for conformance to the requirements of 7.11."

e. In Section 11.1 under "Certification" add the following two sentences after the second sentence now existing.

"It shall be certified that all testing was completed within 30 days prior to shipment from the plant. The supplier shall certify that all pipe and fittings have been protected from direct sunlight from date of manufacture until acceptance by the installer."

Material limitations. The following characteristics of PVC are listed as possible limitations on the use of PVC pipe, to alert the reader and user so that appropriate consideration can be given to them.

a. Unplasticized PVC pipe compounds are brittle at low temperatures. Care must be taken during handling and installation in cold weather.

b. PVC materials may be damaged by accidental exposure to some aggressive fluids, particularly strong solvents, and some oils.

c. PVC pipe may be gnawed by rodents; thus, exposed pipe ends or edges should be protected in areas of known dense populations of rodents. Animal guards should be employed to prevent

animal entry. Termite attack is possible, but has not been recorded as a problem.

d. PVC materials burn; therefore, all "day-lighted" ends or other exposed areas should be protected with nonburning materials or fabricated of some other nonburning material in areas where exposure to flame is possible.

e. Ultraviolet radiation (direct sunlight) rapidly degrades PVC. It should be protected from direct sunlight at all times and outlets, outfalls, or other exposed areas should be protected with light-stable materials or fabricated of some other light-stable material.

ACRYLONITRILE-BUTADIENE-STYRENE (ABS)

General. ABS composite pipe is available with inside diameters of 8, 10, 12, and 15 in. Standard lengths are 6 ft 3 in. and 12 ft 6 in. Although connections have generally been made by solvent welding, elastomeric O-ring joining systems have been developed and are gradually displacing the solvent joints (especially for the large-diameter pipe). A wide range of fittings and connections is available. Table 2 summarizes key characteristics and available information on ABS composite pipe. This table is not a specification; it gives nominal values and properties that can be generally attributed to ABS composite pipe.

Product specifications. The basic specification for this piping system is ASTM D 2680, "Standard Specification for Acrylonitrile-Butadiene-Styrene (ABS) Composite Sewer Piping" (see Appendix A for listing of other applicable ASTM standards).

The scope of the basic specification includes joints, pipe, cementing materials, dimensions, workmanship, stiffness and deflection, chemical resistance, testing, certification, and marking, with an appendix on underground installation.

Recommended modifications of ASTM D 2680.

a. In Section 6.1 delete the words "cell classification 2-2-3" from the first sentence and substitute: "cell classifications which have provided substantial satisfactory service in composite pipe, and which are of a grade capable of receiving a pressure rating in accordance with Method D 1598 to levels required for long-term performance."

Table 2. Acrylonitrile-Butadiene-Styrene (ABS) Composite Sewer Piping for Storm Drains*
(This is not a Specification)

SECTION PROPERTIES (nominal)

Nominal Pipe Diameter (in.)	8	10	12	15
Wt per foot (lbs/ft)	7	9	14	23
Wall thickness (in.)				
Total	1.7	2.0	2.3	2.9
Inner plastic wall	0.060	0.068	0.079	0.096
Outer plastic wall	0.035	0.038	0.048	0.059
Webs	- - - - No Specification - - - - -			
Section Modulus ($in.^3/in.$)	Calculated properties are not valid for pipe because skin buckling and web fracture occur at low deflections.			
Inner wall				
Outer wall				
Moment of inertia ($in.^4/in.$)				

PROPERTIES of ABS Plastic (nominal)

Specific gravity (g/cm^3) (excludes cement in annulus)	1.1
Modulus of elasticity at 73F (psi)	
Short term (minutes)	350,000
Long term (50 years)	?
Tensile strength at 73F (psi)	
Short term (minutes)	4,000
Long term (50 years)	unknown
Coefficient of expansion (in./in./°F)	55×10^{-6}
Fire properties	burns

HYDRAULIC PROPERTIES

Hydraulic coefficient (n)	0.009

BURIAL

Max. depth (ft)	50 manufacturer's claim-not subject to calculation
Min. depth (ft)	2

USE CRITERIA

UV Resistance	nil - store under cover
Rodent attack	unlikely
Microbiological attack	nil
Insect attack	unlikely
Installation temperature limits in field	
Minimum (F)	care needed below 32F
Maximum (F)	none

CHEMICAL RESISTANCE

Run-off	o.k.
Soil	o.k.
Problem contaminants	gasoline, vegetable oils, ketones, esters, chlorinated hydrocarbons

FITTINGS AND CONNECTIONS

Tees	available
Wyes	available
Elbows	available
Connectors	available
Basic connection mode	solvent bonding or gasket

USE CRITERIA

Effects of freezing and thawing (durability)	6 cycles+
Abrasion Resistance (scouring flow rate maximum)	
2 FPS	unknown
10 FPS	unknown
20 FPS	unknown
Cleanout	water jet

* From Reference 2

This change is an attempt to provide some level of assurance that the material used can provide adequate long-term strength. Prior to 1975, only cell classifications 3-2-2, 5-2-2, and 1-3-3 were allowed in ASTM D 2680. Thus, there is a very short record of experience with composite pipe of the new formulation. The 2-2-3 cell classification is not "proven," while there exists an experience record of approximately 10 years with the older classifications. Even nonpressure, nonstructural, drain, waste, and vent pipe (ASTM D 2661) requires a 5-2-2 formulation which can withstand sustained pressure levels.

b. To Section 7, Physical Requirements, add the following new paragraph:

"7.4 Minimum Hydrostatic Burst Pressure--When tested at 23° C (73.4° F) in accordance with 10.7, the minimum burst pressure for pipe shall be 0.48 MPa (70 psi) and for fittings, 1.38 MPa (200 psi)."*

Also add new note as:

"Note 3A--The minimum burst pressure for fittings is different than that for pipe because the fitting walls are thicker than the pipe walls. This test is intended only for the purpose of quality control to ensure that the pipe and fittings have no weak areas, particularly at flow and weld lines. It is not intended to be used as a simulated-service test."

Note 3A explains reasons for the required burst test. The requirement is similar to that of ASTM D 2661 and ASTM D 3311 which cover nonpressure, nonstructural drain-waste-vent pipe.

c. Add new paragraph to Section 10, thus:

"10.7 Minimum Hydrostatic Burst Pressure--The test equipment and procedure shall be as specified in Method D 1599. The test specimens shall be selected at random. Test three specimens of pipe, each ten times the nominal diameter, or a maximum of 9.4 mm (3 ft), long. Test three complete fittings. Test the specimens individually with water under pressure that is increased at an even rate to burst the specimen within a period of 60 to 70 s. Fit one end of the pipe or fitting rigidly to the pressurizing apparatus, and leave the other end free but supported if necessary. Take care to remove all air from the pipe before sealing and testing. Any closure (cap) is suitable if it is free of leaks at maximum test pressure. Condition the specimen in water at 23 ± 1.7° C (73.4 ± 3.0° F) for at least 2 hr before testing. Examine each specimen for conformance to the requirements of 7.4."

---

* Subject to change following development of new ASTM fittings standard.

d. In Section 13, Certification, add the following:

"13.2 Tests shall be performed within 30 days prior to shipment from the manufacturer's plant. The supplier shall certify that all pipe and fittings have been protected from direct sunlight from date of manufacture until acceptance by the installer."

This requirement helps to ensure that the piping material has not been degraded by exposure to ultraviolet radiation.

Material limitations. The characteristics listed below are presented as possible limitations on the use of ABS composite sewer pipe for storm drains or small culverts.

a. ABS material is susceptible to attack by more substances (chemicals) than PVC. Among possible aggressive media are: gasoline, esters (oils), aromatic and chlorinated hydrocarbons, and ketones. Prolonged contact with these materials in high concentrations can cause degradation, deterioration, and failure of ABS pipe.

b. ABS pipe properties deteriorate rapidly when exposed to ultraviolet radiation. This material is more susceptible to damage from direct sunlight than PVC. Pipe should be covered during outdoor storage, and drainage systems should be designed in such a way as to prohibit the use of ABS pipe or fittings in areas where the installed components will be exposed to sunlight.

c. The material burns. Outlets and other locations which may be exposed to fire should be protected through nonburning construction.

d. It is possible that rodents would gnaw ABS pipe, but only a few instances have been recorded. Termite attack, too, is possible, but has not been a problem.

POLYETHYLENE (PE)

General. Corrugated PE tubing is manufactured in a diameter range of 2 to 18 in. The tubing is supplied either with or without perforations. Diameters from 2 to about 6 in. are provided in coils (or rolls); while larger diameters are supplied in straight lengths varying from 2 to 30 ft, depending on diameter and usage. A full range of fittings is available. Table 3 is a summary of key characteristics and available information on corrugated PE drainage tubing. While this table is not

Table 3. Corrugated Polyethylene (PE) Tubing for Underdrains*
(This is not a Specification)

SECTION PROPERTIES (nominal)

Pipe Diameter (in.)	4	6	8	10	12	15	18
Wt per foot (lbs/ft) (one manufacturer's data)	0.3	0.7	1.0	?	2.5	3.6	3.0
Wall thickness (in.)	This data is not normally supplied by manufacturers.						
Area (in.^{2}/in.)							
Section modulus (in.^{3}/in.)							
Moment of inertia (in.^{4}/in.)							
Pipe stiffness - 5% (#/in./in.) (one manufacturer's data)	33	41	34	?	40	43	35
Longitudinal stretch (corrugated pipe only)	-5% to 10%-						

MATERIAL PROPERTIES (nominal)	
Specific gravity (g/cm^3)	0.95
Modulus of elasticity at 73F (psi)	
Short term (minutes)	100,000
Long term (50 years)	15,000
Tensile strength at 73F (psi)	
Short term (minutes)	3,200
Long term (50 years)	800
Brittleness temperature (C)	-60
Coefficient of expansion (in./in./°F)	80×10^{-6}

HYDRAULIC PROPERTIES	
Perforations	
Type	slots or holes
Area (see Basic Specifications)	varies
Hydraulic coefficient (n)	0.013 to 0.018

BURIAL STRENGTH (Margin of Safety)	
Fair embedment (M_s=500 psi)	
10 ft burial	1.5
2 ft burial under H20 wheel load	2.5
High quality embedment (M_s=5000 psi)	
10 ft burial	7
2 ft burial under H20 wheel load	7
Minimum cover under wheel load (ft)	2.0

USE CRITERIA	
Rodent attack	possible
Microbiological attack (clogged slots are a problem with iron bacteria)	nil
Insect attack	possible
Installation temperature–at surface of tubing	
Minimum (F)	40
Maximum (F)	120
Effects of freezing and thawing (durability)	nil
Abrasion Resistance (scouring flow rate maximum)	
2 FPS	unknown
10 FPS	unknown
20 FPS	unknown
Cleanout	water jet only
Fire properties	burns

CHEMICAL RESISTANCE	
Run-off	o.k.
Soil	o.k.
Problem contaminants	strong acids, detergents, some oils and solvents

FITTINGS AND CONNECTIONS	
Tees	yes
Wyes	yes
Elbows	yes
Connectors	yes
Basic connection mode	snap couplings

* From Reference 2

a specification, it does furnish nominal values and properties that apply to corrugated PE tubing in general.

Product specifications. The basic specification for corrugated PE tubing is ASTM F 405, "Standard Specification for Corrugated Polyethylene Tubing" (see Appendix A for listing of other applicable ASTM standards). This specification covers standard and heavy-duty tubing in the nominal sizes of 3 to 8 in., inclusive, in 1-in. increments. The scope of the specification includes materials, marking, dimensions, workmanship, elongation resistance, environmental stress cracking, pipe stiffness, and perforations. The specification also contains an appendix concerning installation.

AASHTO Interim Specifications M 252-751,[3] the BuRec's "Standard Specifications for Polyethylene Plastic Corrugated Drainage Tubing,"[4] and the Soil Conservation Service (SCS) Specifications Guide S-606-1 all have good, applicable requirements, some of which are not contained in ASTM F 405. Therefore, the proposed changes and additions to ASTM F 405 delineated in the next section largely result from their inclusion in the other specifications.

Recommended modifications of ASTM F 405.

a. From Section 2.1, "ASTM Standards," delete reference to "D 1248" and substitute: "D 3350 Specification for Polyethylene Plastics Pipe and Fittings Materials." (See paragraph b below for explanation.)

b. From Section 5.1, "General," delete the entire subparagraph and substitute:

"5.1 General--Compounds used in the manufacture of corrugated PE drainage tubing and fittings shall meet the minimum cell requirements of Class PE324410C (with melt index ≥ 0.6), Class PE 334412C, or PE344412C, as defined and described in Specification D 3350. Density ≥ 0.958 g/cm^3 may be used provided the requirements of 6.5 are met."

This change, and that in subparagraph a above, require that the PE compounds used have the following characteristics:

Density	0.941 - 0.958 g/cm^3
Melt Index	0.15 - 0.6

Flexural Modulus	80,000 - 120,000 psi
Tensile Strength	3,000 - 3,500 psi
Environmental Stress Crack Resistance	50% max at 48 h by test condition A
Hydrostatic Design Basis	1000 psi
UV Stabilizer	2% carbon black

These revisions reflect the use of Specification D 3350, recently adopted, which is a much more definitive specification than D 1248 in controlling tubing resin quality. Furthermore, they eliminate lower density materials that were previously allowed. Also, they introduce a requirement that the resin meet a minimum long-term strength by specifying a HDB of 1000 psi. The HDB is the extrapolated sustained stress level that the material can withstand for 11 yr, based on hydrostatic burst test data accumulated for 1.1 yr.

Also from Section 5.1, delete Note 1 in its entirety. This will maximize resistance to ultraviolet degradation during storage and construction.

c. Several changes should be made in Section 6.

Add the following to Note 2 in subparagraph 6.1.1: "and providing the minimum thickness in any one-foot length is 0.635 mm (0.025 in.)." This quantifies "obvious thin spots" in 6.1.1.

Delete subparagraph 6.2.3 in its entirety. Replace it with the following new paragraph:

"6.6 Perforations--When perforations are necessary, they shall be cleanly cut and uniformly spaced along the length and circumference of the tubing in a size, shape, and pattern in conformance with either Type A or Type B perforations as follows:

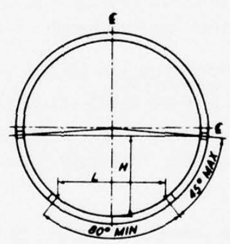
6.6.1 Type A--Perforations of this type in pipe or tubing for underdrains shall be approximately circular and cleanly cut; shall have nominal diameters of not less than 4.8 mm (3/16 in.) nor greater than 9.5 mm (3/8 in.); and shall be arranged in rows parallel to the axis of the pipe. The perforations shall be located on the inside crests (valleys) or along the neutral axis of the corrugations. Pipe connected by couplings or bands may be unperforated within 102 mm (4 in.) of each end of each length of pipe. The rows of perforations shall be arranged in two equal groups placed symmetrically on either side of a lower unperforated segment, corresponding to the flow line of the pipe. The spacing of the rows shall be uniform, and the distance between center lines of the rows shall not be less than 25.4 mm (1 in.). The minimum number of longitudinal rows of perforations, the

maximum heights of the center lines of the uppermost rows above the invert, and the inside surface chord lengths of the unperforated segments are specified in Table 2.

6.6.2 Type B--Type B perforations shall provide a minimum water inlet area of 21.2 cm^2 per m of length (1.0 $in.^2$ per ft of length). The inlets shall be either circular perforations or slots uniformly placed along the length of the pipe or tubing. The rows of perforations shall be equally spaced around the circumference; and there shall be no fewer than three rows. Circular perforations shall not exceed 4.8 mm (3/16 in.) in diameter and slots shall not exceed 3.2 mm (1/8 in.) wide. The slots shall have rounded ends. Slots* shall be no longer than 31.8 mm (1-1/4 in.) for 4-in.-diameter tubing and 38.1 mm (1-1/2 in.) for 6- and 8-in.-diameter tubing. They shall be in the middle of the valley so there is a shoulder on each side of the slot. Tubing with slots on the webs of corrugations, if found to be in conformance with all other requirements, will be permitted. All slots and circular perforations shall be clearly cut with no loose material remaining in the slot or hole."

Following is the new Table 2 to be added:

Table 2. Requirements for Type A Perforations



Diam of Pipe In.	mm	Min Rows of Perforations	H In.	H mm	L In.	L mm
6	150	4	2-3/4	70	3-7/8	98
8	200	4	3-11/16	94	5-1/8	130

---

* Slot length requirements are subject to change depending on results of on-going discussions within the industry.

The Type A perforation configuration was selected from AASHTO M 36 for Zinc Coated (Galvanized) Corrugated Iron or Steel Culverts and Underdrains. The Type B arrangement and sizing are basically the same as those used for land drainage by the BuRec,[4] and the same as required in AASHTO M 252-751.[3] Next, change the second sentence of paragraph 6.3 to read: "Tubing tested shall contain perforations specified, if any." This eliminates any confusion which may result from "if applicable."

Add two new paragraphs to Section 6 as follows:

"6.7 Low Temperature Flexibility--There shall be no cracking permitted when tested in accordance with 8.7.

6.8 Minimum Hydrostatic Burst Pressure--When tested at 23° C (73.4° F) in accordance with 8.8, the minimum burst pressure of pipe shall be that which produces an average stress in the pipe wall of 19.31 MPa (2,800 psi); minimum burst pressure of fittings shall be one-half the burst pressure of the pipe."

Also add new Note 3A:

"Note 3A--The minimum burst pressures for fittings are lower than those for pipe because the geometry, particularly area and radii, is such that the stresses produced in the walls of the fittings are higher than those produced in the pipe walls tested at the same internal pressure. This requirement is intended only for the purpose of quality control and is not intended for use as a simulated-service test."

The minimum burst pressure requirement given above has not been verified; thus, the requirement should be regarded as highly tentative until results of future testing become available.

d. From Section 8 delete subparagraph 8.5.3 entirely and substitute the following:

"8.5.3 Bend the specimens in (on) a suitable fixture such that the chord length during the test, B, is 0.8 ± 1% times the chord length before testing, A."

Also to Section 8, add the following new paragraphs:

"8.7 Low Temperature Flexibility--A minimum of four test specimens of 5-ft lengths shall be conditioned at a temperature of -4° C (24.8° F) for a period of 24 h. The specimen shall then be bent over a 15-in. automobile wheel rim with the 180° bend being completed within 30 s. The specimens shall then be visually inspected for stress cracking in the valleys and sidewalls of the corrugations.

8.8 Minimum Hydrostatic Burst Pressure--The test equipment and procedure shall be as specified in Method D 1599. The test specimen shall be selected at random. Test three specimens of pipe, each ten times the nominal diameter, or a maximum of 914 mm (3 ft), long. Also test three complete fittings. Test the specimens individually with water under pressure that is increased uniformly to cause the specimen to burst within 60 to 70 s. Fit one end of the pipe or fitting rigidly to the pressurizing apparatus, leaving the other end free but supported if necessary. All air must be removed from the pipe or fitting before sealing and testing. Any suitable closure (cap) that is free of leaks at maximum pressure may be used. Condition the specimens in water for at least 2 h at 23 ± 1.7° C (73.4 ± 3.0° F). Examine each specimen for conformance to the requirements of 6.8."

The requirements of paragraph 8.8 may be revised or replaced in the future to reflect the crush test now under development by ASTM.

e. At the end of Section 9.1 add: "A mark shall be provided which is visible around the full circumference of continuous tubing at 3.05 m ± 25.4 mm (10 ft ± 1 in.) intervals, as measured while the pipe is in its natural at rest condition free of longitudinal tension. On pipe or tubing with perforations located only on the lower half of the circumference, the mark shall be provided at the top of the pipe." This additional marking will permit elongation checks during placement in the field.

f. To help ensure that the pipe quality has not been degraded by exposure to ultraviolet radiation during storage, add the following to the second sentence of Section 11.1:

"and that the material meets all the requirements of the specification at the time of shipment from the manufacturer's plant."

Then add the new sentence below to the end of the paragraph.

"The supplier shall certify that pipe has been protected from direct sunlight during storage."

g. To assure use of tubing with adequate strength properties for transportation facilities (i.e., airports or highways) make the following changes to Table 1 of the specification:

Add third column to the table as:

Extra-Heavy-Duty Tubing
40 (0.28)
30 (0.21)
10

Add to the bottom of table as an extra Physical Property Specified: "Pipe Strength, min = 0.34 MPa (50 psi)." Note that although this last requirement is added to minimize crushing damage during storage, handling, and installation, it may not be achievable with present pipe-design concepts.

At the bottom of Table 1 add the following note:

"Note 8--"Standard Tubing" is not recommended for use in transportation drainage facilities."

Material limitations. The following characteristics are possible material limitations on the use of PE corrugated tubing.

a. Experience has shown that PE tubing can deflect 25% or more if not properly installed. Deflections of this magnitude greatly increase chances for stress cracking and long-term stress rupture (collapse).

b. PE is generally chemical resistant; however, long-term exposure to some highly concentrated aggressive fluids may damage the pipe.

c. PE material is more susceptible than most other plastic pipe products to variations in temperature. High temperatures soften it, and low temperatures harden it. This limits the field weather conditions under which the tubing can be installed.

d. Some tubing is supplied with a nylon net wrap for filtration. This net material degrades very rapidly in sunlight--in a period of a few days. Therefore, protection from sunlight is extremely important.

e. PE tubing may be gnawed by rodents or attacked by termites, but neither of these are known to be a problem.

f. This material burns. Therefore take proper precautions against exposure to fire.

g. Although PE tubing is usually affected the least by exposure to sunlight, it can be degraded by long-term exposure to ultraviolet radiation. Pipe and tubing should be protected during storage, and at outlets or other exposed points after installation.

DESIGN, CONSTRUCTION, AND MAINTENANCE GUIDELINES

The tentative guidelines presented in this section are not intended to be comprehensive. The guidelines presented are applicable only to plastic pipe or tubing in general, or to the specific type of plastic

pipe identified. They are intended to be applicable for the plastic pipe materials and products recommended herein for use in airport drainage systems.

These tentatively recommended guidelines are to be used for selection, design, construction, and maintenance of plastic pipe underdrainage and storm and surface drainage systems. Pipe for small culverts is also considered, although most airport culvert applications may require pipe of larger diameter. The guidelines are based on the information obtained and evaluated from the literature, inspection trips, and personal interviews as discussed previously. All considerations, techniques, and methods recommended herein are subject to change due to the results of verification testing and research in the continuation of this project.

DESIGN CONSIDERATIONS

Use and environment.

a. PVC. PVC solid-wall pipe has been used in sanitary and storm sewers, and perforated PVC pipe has been used mainly for leaching beds. Most use of PVC in transportation facility drainage systems has been in municipalities. Users and consultants are nearly unanimous in reporting satisfactory performance of solid-wall PVC pipe in both sanitary and storm sewers. Reasons cited for use include: lack of brittleness, resistance to chemicals and aggressive soils, and competitive cost. Perforated PVC pipe should be applicable as underdrains in airport drainage systems. Unplasticized PVC used in pipe compounds is brittle at low temperatures, and extra care must be taken during installation in cold weather.

The coefficient of thermal expansion of PVC is approximately 5 times that of steel.[6] Thus, thermal expansion of PVC pipe can result in movement up to 3-1/2 in. per 100 ft of pipe per 100° F temperature change. This movement and its possible effects in localities where significant temperature excursions can occur must be accounted for in design and during field installation. Therefore, thermal properties of PVC in comparison to alternative pipe systems can be a selection criterion. Once plastic pipe is buried, temperature excursions, and hence thermal movement of the pipe, are usually greatly reduced. However, under certain conditions, accumulated thermal movements could still be significant and should be accounted for in the design. Short sections ($\leq$ 20 ft) of

gasketed bell-and-spigot pipe can usually accommodate the expected thermal movement.

PVC used for pipe is not affected by freezing and thawing action; however, if any pipe is embedded in or adjacent to soils susceptible to frost heave, it can be seriously affected by soil movement. This movement can cause pipe rupture, change of grade, or loss of seal at connections.

PVC pipe compounds are the most resistant to chemical attack of the three plastic materials chosen herein. Ketones, esters, aromatic and chlorinated hydrocarbons, and vegetable oils can damage PVC.

b. ABS composite. ABS composite pipe was first installed in 1963 in a sanitary sewer system. The principal manufacturer and licenser of this piping product (ARMCO Steel Corporation) claims that almost 8,000 mi are now installed as sanitary sewers. However, there has been very little usage of ABS composite pipe in transportation-related drainage systems. However, most of the multitude of satisfied users of this type of pipe report that it has proven durable and virtually free from any required repairs or any maintenance other than cleaning (which is required less frequently than with most conventional sewer pipe).

Because of the long (relative to other plastic pipe) satisfactory experience record of about 13 years in sanitary sewer applications, ABS composite pipe should be well suited to use as storm sewers and small culverts in airport drainage systems.

The coefficient of thermal expansion of ABS is somewhere between 5 and 12 times that of steel.[6] However, because of the "rigidized" construction of ABS composite pipe (i.e., double-walled, truss-webbed, and filled with foamed mortar), thermal expansion and contraction may be lessened. Still, the possibility of large thermal movements must be considered in the design and in installation.

Although the ABS plastic is not affected by freezing and thawing action, the foam-mortar filler may be. Until data become available to indicate the effects of freeze-thaw on the filler material, ABS composite pipe should be used with caution in applications in which the pipe will be subjected to significant freezing and thawing action. Frost heave can damage any pipe that is buried in or adjacent to frost-active material.

ABS pipe compounds are the most susceptible to chemical attack of the three plastic materials chosen herein. Concentrated oxidizing acids, ketones, esters, aromatic and chlorinated hydrocarbons, gasoline, vegetable oils, glacial

acetic acids, kerosene, and alcohols can damage ABS. Note, however, that these substances must be highly concentrated and in prolonged contact before the ABS is damaged. There have been no confirmed reports of failure due to chemical attack.

c. PE corrugated tubing. This type of plastic tubing, developed in Europe in the early 1960's and introduced into the U. S. in about 1967, has seen increasing use for agricultural land drainage, leach beds, and more recently, in experimental applications as underdrains for highway pavements. With proper design and construction, perforated corrugated PE tubing should perform well as underdrains in airport drainage systems. There are no specifications nor test data available on the performance of fittings. Some connections in PE underdrains are made by using the slightly spiral corrugations as threads. The other widely used method of connecting PE tubing is heat fusion, which is often difficult and costly. Extreme care in selection and compaction of embedment materials at fittings is essential.

In locations where iron bacteria are known to be active, special precautions must be taken to prevent the bacteria from clogging the perforations, especially slots. Use "clean" bedding and backfill materials and provide means for water jet cleanout.

Corrugated PE tubing is believed to be little affected by cyclic stress--significantly less than PVC--but this should be verified by testing or monitored performance under cyclic loads.

Potential rodent attack is of more concern with the use of corrugated PE tubing. The short pitch-length and small radii of the corrugations provide more edges on which small animals can gnaw. However, this has not been a significant problem in past experience. Rodent guards should be installed at pipe ends to prevent animal entry.

PE tubing is most often supplied in coils, each containing about 100 ft. Thus, the number of required connections is minimized compared to all other pipe systems.

The coefficient of thermal expansion of PE is approximately 12 times that of steel.[6] Therefore, thermal expansion of PE tubing can result in movement up to 8 in. per 100 ft of pipe per 100° F temperature change. In localities where significant temperature excursions can occur this movement and its possible effects must be accounted for in design and during construction. However, the corrugations can usually accommodate the expected thermal movements.

PE tubing is not affected by freezing and thawing action; however, if any pipe is embedded in or adjacent to soils susceptible to frost heave, it can be damaged significantly by soil movement.

Strong oxidizing acids, oils, polar reagents such as some detergents, silicones, alcohols, esters, and ketones can affect PE materials. However, as with the other plastics considered herein, while chemical attack is possible, it is not very probable, especially when the PE is used for underdrainage.

Flow characteristics. Smooth-walled plastic pipe has a Manning coefficient (n) of 0.010 to 0.013, generally nearer the smaller value. Some users indicate that the smoothness of the plastic pipe walls reduces the required frequency of cleaning compared to conventional pipe. The Manning coefficient for corrugated PE tubing is between 0.013 and 0.018.

Soil-pipe interaction: expected structural performance. Plastic pipe can be categorized as "flexible" compared to the stiffness of the surrounding soil, as determined from current theories for soil-structure interaction. The further complex behavior introduced by plastics characteristics has, nevertheless, seldom been accounted for. Structural design procedures for buried plastic pipe must take into account the following factors which affect structural behavior and adequacy:

Soil interaction with pipe structure as it affects magnitude and distribution of earth and surface loads which act on the pipe.

Bending and axial stresses and deflection of the pipe ring (section) which result from combined soil-pipe behavior.

Buckling resistance of soil-supported pipe.

Effect of time-temperature dependent structural characteristics of plastics on the soil-pipe system.

Long-term strength of plastic pipe materials, depending on time, temperature, other environmental effects, and cyclic fatigue characteristics.

The most common criterion for the design of and evaluation of buried flexible plastic pipe is deflection. This approach has derived from design methods for corrugated metal pipe (i.e., Spangler theory[7]). However, unlike in metal pipe where high bending stresses do not necessarily cause failure, bending stresses and strains in plastic pipe are

important enough that any evaluation of the performance of buried plastic pipe should recognize stress and strain in the pipe wall.

a. Analyses for stresses and deflections in buried flexible pipe. NCHRP Report No. 116 by Krizek et al.[8] essentially reflects the state of the art in analysis of flexible and semirigid pipe. The report indicates that there are many divergent approaches to the problem. Still others have been identified and evaluated during recent study.[2]

The Burns and Richard (B&R) approach, recommended by Krizek et al.,[8] and further developed by Lew[9] and Katona et al.[10] is based on an idealized system consisting of an elastic ring (pipe cross-section) surrounded by a semi-infinite elastic plate (soil) with loads applied to the boundaries of the plate.

The B&R solution needs modification to account for field variations from the idealized uniformity of embedment material assumed in the model. Calculated bending stresses are multiplied by a Tentative Bedding Factor (TBF) of 2 to account for bedding. It may be necessary to modify deflections in a similar manner, depending on results of future studies. Watkins (see Bibliography; Watkins et al., 10 references) and many other investigators of buried plastic pipe share the view that deflection of the buried pipe provides a measure of bending stress in the pipe wall. They further imply that, at equal deflections, the maximum bending stress in the buried condition is the same as that in a ring subject to diametral compression (i.e., parallel plate test).

The B&R solution predicts that, at equal deflections, the maximum bending stress in buried pipe is $\leq 2/3$ the stress in a ring subject to diametral compression. Considering the ring compression stress which actually develops in the buried condition, and a TBF = 2 above, the B&R solution predicts that the maximum combined stress in the pipe wall is equal to or less than that which occurs in a ring under the same deflection. Both findings are significant since simple deflection measurements can be used to estimate stresses in the pipe wall.

The above stress-deflection relationship under buried conditions, compared to the stress-deflection relationship in the parallel plate test, has not been verified adequately by buried pipe tests; limited data by BuRec (see Bibliography; Howard et al., 14 references) seem to confirm its validity.

Buckling criteria as proposed by Chelepati in Reference 11 and incorporated into the Culvert Analysis and Design Program (CANDE) now being developed by Katona et al.[10] appear appropriate for the evaluation of buried plastic pipe.

b. Procedures for evaluating structural performance.[2] The following procedures are the combined result of the above review of soil-pipe interaction analysis methods, and an analysis of information available on plastic pipe materials and design methods.

(1) Short-term structural performance is determined and evaluated according to the following steps:

S-T-1 The short-term stresses and deflections are calculated, using the short-term pipe stiffness properties and soil stiffness, by the B&R solution.

S-T-2 Bending stresses are multiplied by the TBF = 2 for bedding effects and then they are combined with ring compression stresses to determine the maximum short-term extreme fiber stresses.

S-T-3 Maximum extreme fiber stresses are compared to the short-term tensile yield strength of the material to determine the margin of safety against yield in the short term. Maximum stresses are always compression because ring compression stresses add to the equal tension and compression extreme fiber stresses which result from bending.

S-T-4 The Chelepati solution is used to evaluate short-term stiffness of the pipe and soil stiffness.

S-T-5 The ring compression stress as determined above is compared to the critical buckling stress to determine the margin of safety against buckling. Presently, possible decreases in buckling strength due to bending are neglected.

(2) Long-term structural performance is determined and evaluated according to the following steps:

L-T-1 The maximum short-term strain is determined from the maximum extreme fiber stress determined in S-T-2 above, using short-term modulus of elasticity values.

L-T-2 Except for the effect of soil consolidation noted below, the short-term extreme fiber strain is assumed to remain constant (in "good" embedment materials). That is, the decrease in modulus of the plastic with time (flexural relaxation and compression creep) does not affect strain or deflection significantly in the long term.

L-T-3 The short-term extreme fiber strain, ring compression stress, and deflection are increased by a factor of

1.5 to account for long-term consolidation of the soil around the pipe (i.e., Spangler's deflection lag factor, which is observed even on elastic metal pipe).

L-T-4 The margin of safety against failure in the long term is determined by comparing the extreme fiber strain (L-T-3) to the initial strain which will produce failure (collapse) after relaxation for 50 years (termed here the "ultimate strain"). This ultimate strain is estimated from allowable strains for pipe material under relaxation conditions as established by the Scandinavian Underground Pipe Committee and reported by Molin.[12] (The inference is that the allowable strain is 1/2 of the "ultimate strain," but this needs verification.)

L-T-5 The Chelepati solution is used to evaluate long-term critical buckling stress, using long-term stiffness of the pipe as estimated from creep data.

L-T-6 The long-term ring compression stress (L-T-3 above) is compared to the critical buckling stress to evaluate the margin of safety against buckling in the long term.

(3) Performance of PVC under cyclic surface wheel loads is determined and evaluated according to the following method. This is a tentative method, and only for PVC because it displays significant loss of strength under cyclic loading. This method must be verified in future study and methods of evaluating other plastic pipe under cyclic loading should be developed.

W-L-1 Cyclic stresses due to wheel loads are calculated as in S-T-1, S-T-2, and S-T-3 above.

W-L-2 The cyclic extreme fiber stresses are compared to the cyclic fatigue strength (endurance limit) as determined from cyclic hydrostatic fatigue tests on pressure pipe. The margin of safety against failure by cyclic fatigue is thus determined.

(4) The minimum factor of safety should be between 2 and 3 for transportation-related drainage systems. An increase in required factor of safety is warranted, based on the judgment of the engineer, depending upon the consequences of failure (e.g., under deep fills under runways or roadways, or where risks of failure of a large structure are involved).

CONSTRUCTION/INSTALLATION GUIDELINES

General. The following tentative construction guidelines have been developed to furnish to the designer and installer the requirements for installation of the plastic pipe systems chosen herein as most usable. The proposed tentative standards were developed from existing ASTM specifications, and user agency specifications, with modifications suggested to upgrade installed product quality and to relate installation practice to requirements of the plastic pipe products.

Tentative guidelines for the installation of plastic underdrains.

a. Introduction. Perforated pipe underdrains can be provided beneath airport or highway pavements to collect water from a drainage blanket in the base course or subbase, or below shoulders to lower the natural water table. Nonperforated pipe is also used in the system to convey collected waters to a discharge point away from the pavement area. Such installations usually require from 2 to 6 ft of cover from the crown of pipe to roadway or shoulder surface.

Underdrains are usually surrounded by a drainage envelope of selected granular material which precludes infiltration of soil particles through the perforation holes or slits of the pipe and which is graded to preclude clogging of the blanket by excessive infiltration of fines. The selected material also functions as a foundation and side support layer which interacts with the pipe structure in the support of surface wheel loads and earth cover loads. As an alternative to the use of a graded granular envelope, an external filter sleeve, such as nylon screening, encircling the underdrain tubing can serve as a drainage envelope in a granular backfill which is not adequately graded.

The structural performance of a thermoplastic underdrain pipe installation is governed by the system of soil bedding, soil side support, and pipe structure which is provided in the completed installation. Ability to resist wheel and earth cover loads is more dependent on the properties of the earth structure which immediately surrounds the pipe than on the properties of the pipe structure itself. However, two essential structural requirements must be provided in the pipe structure in order for this to be true:

(1) The pipe must be stiff enough and rugged enough to withstand effects which result during handling and installation. A pipe stiffness value of 25 psi (40 psi for corrugated polyethylene) at 5 percent deflection is

generally considered minimum for thermoplastic pipe. This minimum stiffness should be increased to 35 psi (40 psi for corrugated polyethylene) for applications below runways, taxiways, aircraft parking aprons, streets, highways, and shoulders which are likely to be subject to heavy wheel loads at shallow burial during construction and in long-term service.

(2) The pipe must be strong enough to withstand stresses which develop during interaction with surrounding soil as the pipe-soil system deflects under load. Generally, for the more flexible types of plastic pipe, strength must be sufficient to safely withstand stresses associated with up to 3 percent reduction of vertical diameter under long-term service loads and soil consolidation.

Uniformity of bedding is required to preclude the introduction of excessive longitudinal bending because the pipe tends to "bridge" across soft or low spots in the bedding. Corrugated underdrain tubing has little longitudinal stiffness and thus more easily conforms to longitudinal irregularities in bedding than smooth-wall pipe.

Several existing and proposed ASTM specifications cover installation of buried thermoplastic pipe. However, none of these specifications is suited to the application of thermoplastic pipe for pavement and shoulder underdrains. In view of this, a tentative standard "Recommended Practice for Installation of Flexible Thermoplastic Underdrain Pipe for Pavements and Shoulders" (after Reference 2) is suggested herein, based on the above-mentioned existing specifications together with the results of research by the Federal Highway Administration (FHWA), the BuRec, the SCS, the Federal Aviation Administration (FAA), the U. S. Army Corps of Engineers (CE), and many plastic pipe manufacturers, and consideration of recent practice in several state highway departments. The standard is presented henceforth in ASTM format.

b.

TENTATIVE STANDARD RECOMMENDED PRACTICE FOR INSTALLATION OF FLEXIBLE THERMOPLASTIC UNDERDRAIN PIPE FOR PAVEMENTS AND SHOULDERS

1. Scope.

1.1 This recommended practice describes arrangements and installation procedures for both smooth-wall and corrugated-wall thermoplastic underdrain pipe for drainage of transportation facilities. Both perforated pipe which serve as drainage collectors, and nonperforated pipe which drain the collector pipe, are included. Installation requirements to achieve both flow capacity for drainage collection and

pipe-soil structural interaction for support of surface wheel loads and earth cover loads are provided.

1.2 Because of limited experience with thermoplastic underdrain piping, the following limitations are to be applied to the use of this recommended practice.

1.2.1 Maximum inside diameter of pipe: 305 mm (12 in.) for smooth-wall poly (vinyl chloride) (PVC) pipe and 203 mm (8 in.) for corrugated polyethylene (PE) pipe.

1.2.2 Thermoplastic pipe materials covered by this recommended practice are: smooth-wall PVC (ASTM D 3033 and D 3034, as modified in PIPE MATERIALS - PROPERTIES AND CHARACTERISTICS, PVC), and corrugated PE (ASTM F 405, as modified in PIPE MATERIALS - PROPERTIES AND CHARACTERISTICS, PE).

2. General Arrangement.

2.1 Install plastic pipe underdrains in trenches with dimensions and arrangement as shown on the plans. Surround perforated underdrain piping with a compacted granular drain envelope as specified herein. Place perforated pipe with perforations below the horizontal diameter unless otherwise specified. Surround nonperforated underdrain pipe with a compacted granular material as specified herein. Minimum thickness of drain envelope or other granular material is 152 mm (6 in.) at the sides, 4 in. at the bottom, and 152 mm (6 in.) above the pipe.

2.2 Where the subgrade into which underdrains are to be placed is built up as an embankment, first place and compact embankment as specified to a minimum height of 152 mm (6 in.) above the top of the underdrain pipe, then excavate trenches for underdrains and install pipe.

3. Terminology. Figure 1 shows a cross section through a typical underdrain installation and defines terminology to be used to describe the various embedment and foundation regions adjacent to the pipe.

4. Trench Excavation.

4.1 Excavate underdrain trenches to the dimensions and grades shown in the plans, or as directed by the Engineer. Minimum width of trench is 610 mm (24 in.), or pipe diameter plus 305 mm (12 in.), whichever is greater, if in soil; and pipe diameter plus 305 mm (12 in.), if in rock.

4.2 Excavate in such a manner that the undisturbed state of soils below and beyond the required excavation limits are preserved and that the bottom of the trench is maintained firm, dry, and in all other respects acceptable to the Engineer.

4.3 Where unstable or running soil conditions are such that trench walls will not remain vertical, stabilize this condition prior to preparing bedding and laying pipe. If, in the extreme case, sheeting and bracing are required, details of the support system should be submitted to the Engineer for review. Consideration should be given to leaving in place any portion of the sheeting or trench protection that extends below the top of the pipe, to preserve needed side support.

4.4 If a trench is excavated to a width of 152 mm (6 in.) or more greater than the required width or to an excess depth which is more than 102 mm (4 in.) below the required distance from pipe invert to trench bottom, apply to the Engineer for materials and compaction requirements for backfilling the excess excavation.

5. Foundation.

5.1 Foundation materials must provide stable conditions for support of piping. In general, foundation conditions which are suitable for pavement support are also suitable for underdrain piping.

5.2 If unsuitable soil conditions are encountered at foundation level, the Engineer may direct that they be removed to a specified depth below pipe invert grade and replaced with suitable bedding material meeting specified requirements for the drain envelope.

6. Embedment Materials.

6.1 Embedment materials (Figure 1) include the granular drain envelope layer to be used with perforated pipe and other materials for use with perforated pipe containing external filter screening and nonperforated pipe.

6.2 Drain Envelope Layer - Clean granular material free of particles finer than #100 sieve having gradation and particle size characteristics in conformance with Table 1.

6.2.1 Where slot widths are less than 2.5 mm (0.10 in.), or hole diameters are less than 3.6 mm (0.14 in.), a one-course drain envelope consisting of coarse sand having the approximate gradation characteristics given in Table 2 is acceptable for most applications. Minimum dimensions of the one-course drain are given in 2.

6.2.2 Where a suitable external filter screed sleeve is used, a one-course drain envelope consisting of concrete sand, ASTM C 33, or other clean granular well-graded sand, as available from in situ sources, is acceptable.

6.2.3 Where slot widths of hole diameters are greater than the limits given in 6.2.1, and where no filter screen sleeve is provided, use a 2-course filter envelope consisting of 9-mm (3/8-in.) maximum size

graded crushed stone for a minimum radial distance of 152 mm (6 in.) completely surrounding the pipe (except 102 mm (4 in.) below bottom is acceptable), and concrete sand, ASTM C 33, in an outer blanket extending for a minimum radial distance of 152 mm (6 in.) completely surrounding the pipe and stone blanket (except 102 mm (4 in.) below bottom is acceptable).

6.3 Where the pavement subbase contains a two-course drainage layer consisting of a coarse stone drain over a coarse sand filter, the sand filter course should extend beneath the underdrain pipe as the bedding layer and the coarse stone drain layer should surround at least the upper 90 percent of the pipe. Minimum dimensions of the drain envelope are given in 2.

6.4 Bedding, haunching, and initial backfill materials where pipe is not perforated:

6.4.1 Class I - Angular. 6.4 to 12.7 mm (1/4 in. to 1/2 in.) graded stone, including a number of fill materials which have regional significance such as coral, slag, cinders, crushed stone, and crushed shells.

6.4.2 Class II - Coarse sands and gravels with maximum particle size of 12.7 mm (1/2 in.) including variously graded sands and gravels containing small percentages of fines, generally granular and noncohesive either wet or dry (soil types GW, GP, SW, and SP).

6.5 Bedding, haunching, and initial backfill materials where pipe is not perforated and where surface wheel loading (either from final service or from construction operations) is not a design load: soil types given in 6.4, or:

6.5.1 Class III - Fine sand and clay gravels, including fine sands, sand-clay mixtures and gravel-clay mixtures (soil types GM, GC, SM, and SC).

7. Bedding.

7.1 Bed the pipe true to line and grade with uniform and continuous support from a firm base. Do not use blocking to bring the pipe to grade. Provide thickness of drain envelope materials given in 2., or 6.2.3 for two-course envelope.

7.2 Compact coarse sand drain envelope materials and Class II bedding materials to 85 percent AASHTO T99 Density and Class III materials to 90 percent AASHTO T99 Density. Class I and stone drain envelope materials need only be firmly and uniformly tamped or vibrated to proper grade. Do not use frozen material or materials with lumps in excess of 25.4 mm (1 in.) maximum size.

7.3 Provide a bedding groove or furrow which conforms approximately (within 6.4 mm (1/4 in.)) to the lower 90 degrees of the pipe circumference for all installations designed for surface wheel loading. Installations not designed for surface wheel loading need not utilize a bedding groove if "haunching" backfill is carefully worked under the haunches of the pipe.

7.4 If pipe contains "bell-and-spigot" type joints, place bells "uphill," and excavate bell holes in bedding to allow for unobstructed assembly of the joint. Maintain minimum size bell hole necessary to accomplish proper joint assembly. After joint is made, fill bell hole with compacted bedding or haunching material to provide uniform bedding support for the pipe throughout its entire length.

8. Handling and Installation of Pipe.*

8.1 When pipe materials are supplied in straight lengths, store on flat surfaces so as to support barrel evenly, with bell ends, if any, overhanging no more than 610 mm (2 ft). If intermediate supports are used, maximum spacing is 1 m (3 ft). Pad contact areas to avoid damage to pipe. Do not stack in piles higher than 1.6 m (5 ft). Protect pipe from sunlight by covering during storage longer than 5 days (2 days for corrugated PE pipe with external plastic fabric filter sleeve) and by backfilling open trenches within 5 days after uncovering pipe.

8.2 Handle pipe in such a way as to avoid damage. Do not slide pipe over rough surfaces. Avoid all types of impact, especially during cold weather; e.g., dropping hard, sharp, or heavy objects on pipe or hitting pipe against stationary objects. Remove and replace any pipe with cracks, local bulges or buckles in excess of 1 percent of the inside diameter, scratches deeper than 5 percent of the pipe wall thickness, or connecting ends which do not mate properly with adjacent pipe.

8.3 When corrugated PE tubing is installed by machine, limit longitudinal stretch to 5 percent. Do not apply excessive pull.

8.4 In cold weather, use care not to crack coiled tubing during uncoiling; take precautions to maintain straightness.

8.5 Lay pipe firmly in bedding grooves, where required, true to lines and grades shown on the drawings, or as established by the Engineer.

8.6 Connect perforated collector pipe with tightly fitting friction socket or other joints which firmly hold the connected pipe in position. Solvent cement or other positive connection is not required, but can be used.

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* Subject to change to include recommendations in PPI Technical Report PPI-TR 26, May 1975.

8.7 Connect nonperforated collector drain pipe with solvent cemented or other positive-connecting joints which firmly hold the connected pipe in position and prevent longitudinal separation of the pipe if subjected to longitudinal forces.

8.8 Provide suitable fittings at all joints; changes in direction, changes in diameter, branch connections, and ends of line. Use only fittings supplied by the manufacturer of the pipeline system.

9. Haunching and Initial Backfill.

9.1 In the haunch region (Figure 1), place the drain envelope (or in the case of nonperforated drains, Class I, II, or III material) carefully beneath and around pipe to the spring line in 152-mm (6-in.) thick, maximum, layers and compact to 90 percent AASHTO T99 Density by tamping, vibration, flooding (drain envelope or Class II only, with approval of the Engineer), or a combination thereof. Use only Class I materials in the haunch region, if this material is used for bedding. Work material beneath and around the pipe to preclude void areas adjacent to the pipe and compact firmly. Prevent movement of the pipe during placement of haunch material. If mechanical compaction equipment is used, avoid contact with the pipe and replace and re-lay any sections of pipe damaged (as defined in 8.2) during compaction.

9.2 In the initial backfill region (Figure 1) place the drain envelope, or in the case of nonperforated drains, Class II or III backfill material in 203-mm (8-in.), maximum, layers and compact to 90 percent AASHTO T99 Density by tamping, vibration, flooding (drain envelope or Class II only, with approval of the Engineer), or a combination thereof. For Class I backfill, tamp or vibrate material firmly in place around entire drain. Do not compact zone above pipe until 152 mm (6 in.) or more of material is in place over the top of pipe.

9.3 For designs which provide for surface wheel loads, backfill above the "initial backfill region" with material and compaction as specified for pavement subbase or shoulder, as appropriate. For designs which do not provide for surface wheel loads, backfill above the initial backfill region with native materials and no special compaction, unless otherwise shown in the plans or specifications.

10. Minimum Cover.

10.1 Provide the following minimum total cover thicknesses between top of pipe and pavement or ground surface in the cases of flexible pavements or unsurfaced traffic areas, except that unless the drainage facility is specifically designed to drain one or more layers of the flexible pavement structure, the pipe shall not be less than 305 mm (1 ft) below the top of the undisturbed subgrade in grade or cut sections, or below the bottom of the lowest structural pavement layer in fill sections. The backfill between either the top of the pipe and the top

of the undisturbed subgrade or the top of the pipe and the unpaved trafficked surface shall be compacted granular material, Class I or II.

10.1.1 The minimum total cover thickness over PVC underdrain pipe, with minimum pipe stiffness of 0.24 MPa (35 psi) at 5 percent deflection, is 762 mm (30 in.).

10.1.2 The minimum total cover thickness over corrugated PE tubing, with minimum pipe stiffness of 0.28 MPa (40 psi) at 5 percent deflection, is also 762 mm (30 in.).

10.2 Underdrains under rigid pavement shall be installed a minimum of 381 mm (15 in.) below the bottom of the slab (i.e., between top of pipe and bottom of slab).

10.3 For installations not subject to surface-applied wheel loads, provide a minimum cover of 305 mm (1 ft) above the top of the pipe.

10.4 Provide at least 1.22 m (4 ft) of cover before using a hydrohammer for compaction.

10.5 To prevent heaving of pipe in frost-susceptible subgrades, and to prevent freezing of water in the pipe, the pipe should be placed below the depth of maximum frost penetration.

11. Machine Installation. Machine methods of trenching, pipe laying, and backfilling may be used if they do not stretch PE tubing in excess of the limits specified herein, and if they provide the compaction requirements of this Recommended Practice and the alignment and grade tolerances shown on the plans or specifications. Pipe shall not be installed by mole plow.

12. Deflection Check.

12.1 Check that deflection of the completed installation is not more than 3 percent by pulling a test mandrel or suitable deflectometer through the line.

12.2 This check is to be carried out 30 to 60 days after completion of pipe backfill, or just prior to construction of pavement above the line, whichever is sooner.

12.3 If deflection exceeds 3 percent, remove and replace pipe installation in zone of excess deflection.

13. Outlet Sections.

13.1 Provide an animal guard at outlet pipes and at any other points where animals can enter the pipeline system.

Table 1. Drain Envelope Characteristics

For Rectangular Slots:	D_{85} drain envelope $\geq$ 1.4 times slot width
For Circular Holes:	D_{85} drain envelope $\geq$ 1.2 times hole diameter
For All Types of Perforated Underdrain Pipe:	D_{15} drain envelope $\geq$ 5 D_{15} surrounding soil
	D_{15} drain envelope $\leq$ 5 D_{85} surrounding soil
	D_{50} drain envelope $\leq$ 25 D_{50} surrounding soil
	Not more than 2% of drain envelope may pass the #100 sieve
	In medium to highly plastic clay soils without sand or silt partings, the D_{15} size of the drain envelope may be as great as 0.4 mm and the D_{50} criteria given above may be disregarded if the drain envelope is well graded and has a ratio of D_{60} to D_{10} not greater than 20

Table 2. Coarse Sand Gradation for One Course Drain Envelope

Sieve Size	3/8 in.	No. 4	No. 16	No. 50	No. 100
Range in Allowable Percent Passing	95-100	80-90	45-65	10-25	0-2

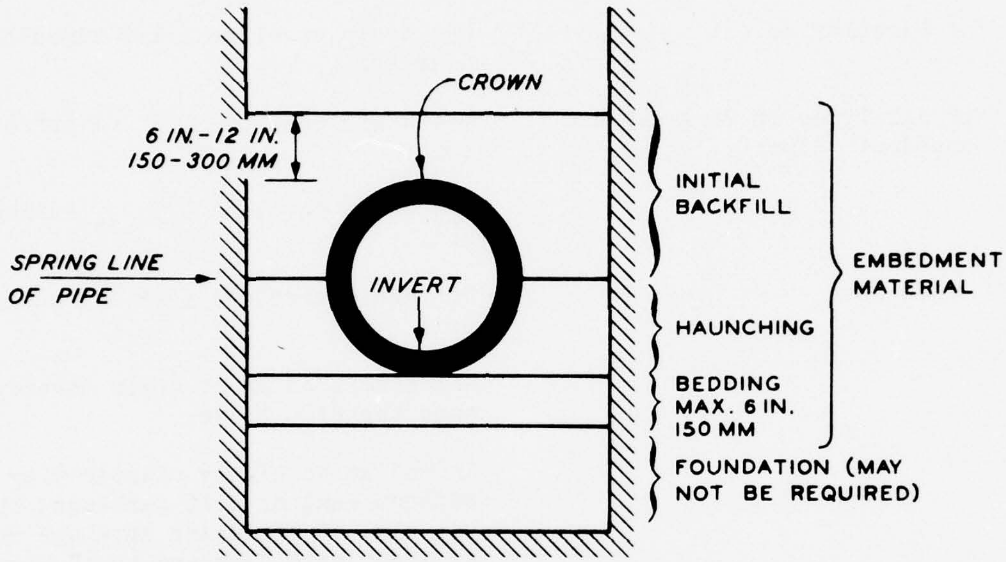

Figure 1. Trench cross section showing terminology relationships for typical underdrain pipe (after Reference 2)

13.2 Do not expose plastic outlet pipes to sunlight.

13.3 Protect plastic outlet pipes from ground-cover fines.

Tentative guidelines for the installation of plastic storm drains and small culverts.

a. Introduction. PVC and ABS composite piping systems have been used for storm drains in highways and urban streets, as well as for municipal sanitary sewers below streets. These types of plastic pipe are designed to act as "flexible" pipe within an installed soil-pipe system whose structural performance is governed by the system of soil bedding, soil side support, and pipe structure which is provided in the completed installation. Ability to resist substantial wheel and earth-cover loads is more dependent on the properties of the earth structure which immediately surrounds the pipe than on the properties of the pipe structure itself. However, two essential structural requirements must be provided in the pipe structure in order for this to be true:

(1) The pipe must be stiff enough and rugged enough to withstand effects which result during handling and installation. A pipe stiffness value of 25 psi at 5 percent deflection is generally considered minimum for thermoplastic pipe. This minimum stiffness should be increased to 35 psi for applications below runways, taxiways, aircraft parking aprons, streets, highways, and shoulders which are likely to be subject to heavy wheel loads at shallow burial during construction, or in long-term service. Composite ABS pipe should have a minimum stiffness of 200 psi at 5 percent deflection.

(2) The pipe must be strong enough to withstand stresses which develop during interaction with surrounding soil as the pipe-soil system deflects under load. Generally strength must be sufficient to safely withstand stresses associated with up to 3 percent reduction of vertical diameter and increase of horizontal diameter under long-term service loads and soil consolidations.

ASTM Standard D 2321, "Standard Recommended Practice for Underground Installation of Flexible Thermoplastic Sewer Pipe," has been used widely in specifications for the installation of plastic sewer pipe. This standard recommended practice may be referenced as the basic specification for installation of PVC and ABS composite storm drain and small culvert piping in transportation facilities. However, modifications and additional criteria are suggested in the next section as appropriate for the specific application of these types of plastic pipe and storm drains and culverts.

b. Tentative recommended modifications to ASTM D 2321.*

(1) Change the first sentence in Section 1.1 to read:

"1.1 This recommended practice describes procedures for installing single-wall thermoplastic sewer pipe and double-wall or composite thermoplastic sewer pipe in excavated trenches."

(2) In paragraphs 6.1.1, 6.1.2, and 6.1.5 of Section 6 delete the 40 mm (1-1/2 in.) particle size and substitute:

"20 mm (3/4 in.)."

Also, add new paragraph 6.2 as follows:

"6.2 Use only Class I and II embedment materials when pipe is installed under pavements or where surface wheel loading is a design loading (during construction or in-service)."

(3) Add the following new paragraph to Section 8:

"8.1.5 Bedding Groove--Provide a bedding groove or furrow which conforms approximately (within 6.4 mm (1/4 in.)) to the lower 90 degrees of the pipe circumference for all installations designed for surface wheel loading. Installations not designed for surface wheel loading do not require a bedding groove if haunching backfill is properly installed (i.e., carefully worked under the haunches of the pipe and properly compacted)."

(4) To Section 9.1 add the following sentence:

"Also included are recommended practices for handling pipe components."

Then add the following new paragraphs:

"9.1.4 Storage--Store pipe on flat surfaces to support the barrel evenly. If spacer blocks (to support pipe in the bottom layer of a stack so that bell ends are not stressed by being in contact with the storage surface) or intermediate supports are used the maximum spacing along the pipe is 1 m (3 ft). Maximum overhang of bell ends is 610 mm (2 ft). Do not stack in piles higher than 1.6 m (5 ft). Protect pipe from sunlight by covering during outdoors storage longer than 5 days and by backfilling open trenches within 5 days after uncovering the pipe.

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* Subject to change to include recommendations of PPI Technical Report PPI-TR-26, May 1975.

9.1.5 Handling--Handle pipe in such a way as to avoid damage. Do not slide pipe over rough surfaces. Avoid all types of impact, especially during cold weather; e.g., dropping hard, sharp, or heavy objects on pipe or hitting pipe against stationary objects. Remove and replace any pipe with cracks, local bulges or buckles in excess of 1 percent of the inside diameter, scratches deeper than 5 percent of the pipe wall thickness, or connecting ends which do not mate properly with adjacent pipe.

9.1.6 Laying--Lay pipe firmly in bedding grooves, where required, true to lines and grades shown on the drawings, or as established by the Engineer.

9.1.7 Connections--Connect pipe with solvent-cemented, gasketed bell-and-spigot, or other positive connecting joints which hold the connected pipe firmly in position and prevent longitudinal separation of the pipe joint if subjected to longitudinal forces.

9.1.8 Fittings--Provide suitable fittings at all joints, changes in direction, changes in diameter, branch connections, and ends of line. Use only fittings supplied by the manufacturer of the specific system being installed.

9.1.9 Backfill--For designs providing for surface wheel loads, backfill above the "initial backfill region" (see Figure 1) with material and compact as specified for pavement subbase or shoulder, as appropriate. For designs which do not require provision for surface wheel loads, backfill above the initial backfill region with native materials; compaction is not needed unless otherwise required in the plans or specifications."

(5) The sentence forming Section 10.1 should be changed to read:

"10.1 For pipe stiffness requirements for designs which do not require provision for surface wheel loads, see Appendix."

Then add the following new paragraph:

"10.2 For designs which provide for surface wheel loads, the minimum pipe stiffness shall be 0.24 MPa (35 psi) at 5 percent deflection (1.38 MPa (200 psi) at 5 percent deflection for ABS composite pipe)."

(6) In Section 11, delete the existing paragraph 11.2 and replace with the following:

"11.2 Minimum Cover:

11.2.1 Provide a minimum total cover thickness between top of pipe and pavement or ground surface in the cases of flexible pavements or unsurfaced traffic areas of 762 mm (30 in.); except that the top of the pipe shall in no case be less than 305 mm (1 ft) below the top of the undisturbed subgrade in grade or cut sections, or below the bottom of the lowest structural pavement layer in fill sections. The backfill between either the top of the pipe and the top of the subgrade or the top of the pipe and the unpaved trafficked surface shall be compacted granular material, Class I or II.

11.2.2 Pipe installed under rigid pavement shall be installed a minimum of 381 mm (15 in.) below the bottom of the slab (i.e., between top of pipe and bottom of slab).

11.2.3 For installations not subject to surface-applied wheel loads, provide a minimum cover of 305 mm (1 ft) above the top of the pipe.

11.2.4 Provide at least 762 mm (30 in.) of cover over the top of the pipe before the trench is wheel loaded, and 1.22 m (4 ft) of cover before using a hydro-hammer for compaction.

11.2.5 In areas of seasonal frost, the pipe should be installed at the minimum depth shown in Table 1."

Also add following new paragraphs:

"11.5 Machine Installation--Mechanized methods of trenching, bedding, pipe-laying, and backfilling may be used if they provide all of the requirements of this recommended practice and the alignment and grade required in the plans and specifications.

11.6 Outlets or Outfalls.

11.6.1 Provide an animal guard at all pipe outlets and at any other points where animals can enter the pipeline system.

11.6.2 Do not expose plastic pipe outlets to sunlight.

11.6.3 Protect plastic outlet pipes from ground-cover fires."

(7) Add an entire new section as given below:

"12. Deflection Check.

12.1 Check that deflection of the completed pipe installation is not more than 3 percent by pulling a test mandrel or a suitable deflectometer through the pipeline. This check shall be carried out 30 to 60 days after completion of pipe backfill, or just prior to construction of pavement above the pipe, whichever is sooner. If deflection exceeds 3 percent at the time of the check, remove and replace the affected pipe length."

Table 1

Minimum Pipe Cover Requirements for Protection of Storm Drains and Culverts in Seasonal Frost Areas

(From Corps of Engineers Technical Manual 5-820-3)

	Nonfrost-Susceptible Subgrade		Frost-Susceptible Subgrade	
Position of Water Table	To Prevent Heave	To Prevent Freezing of Water Flowing in Drainpipe	To Prevent Heave	To Prevent Freezing of Water Flowing in Drainpipe
Not over 5 ft below maximum depth of frost penetration	No measures required	Place invert of pipe at or below depth of maximum frost penetration	For pipe diameters smaller than 18 in. place centerline of pipe at or below depth of maximum frost penetration. For pipe diameters 18 in. or larger place centerline of pipe 1/3 diameter below depth of maximum frost penetration or place drained, highly free draining, nonfrost-susceptible material around pipe and place centerline of pipe at depth of maximum frost penetration.	Place invert of pipe at or below depth of maximum frost penetration
5 ft or more below maximum depth of frost penetration	No measures required	Place invert of pipe at or below depth of maximum frost penetration	Place centerline of pipe at or below depth of maximum frost penetration	Place invert of pipe at or below depth of maximum frost penetration

Note:

1. For any given situation, the criterion requiring greatest depth of pipe burial will control; frequently cover required for traffic loads will exceed that needed for frost penetration.
2. Entrances and exits, as of culverts, require granular backfill to restrict frost penetration to nonheaving materials.
3. For short pipes exposed to cold air, design will be based on local icing experience. If necessary, extra-size pipe will be provided to allow for icing.

MAINTENANCE TECHNIQUES

Cleaning. Cleaning the installed storm sewer, collector drain, or underdrain is likely to be the single most important maintenance concern of the installation owner/operator. Generally, the smooth surfaces of uncorrugated plastic pipe walls prevent or significantly inhibit clogging; however, it is recommended that all plastic pipe installations be thoroughly cleaned on an annual basis with a suitable water-jet cleaning device. Do not use scraping- or abrasive-type cleaning devices in plastic pipe. Corrugated-pipe underdrains should also be cleaned annually with a suitable water-jet device. Frequent water-jet cleaning is especially important for perforated-pipe underdrains when they are installed in soil environments that contain iron bacteria. Frequent cleaning is also a possible inexpensive method of maintaining serviceability of underdrains around which the drain envelope was improperly designed or installed.

Maintaining outlets. An annual inspection of all outlets or other potentially exposed areas is recommended. Wherever and whenever pipe is found that is unprotected from sunlight, immediate action is required to provide the necessary protection. This may mean restoring the integrity of the original protective means, installing or applying new protection, or removing and replacing damaged pipe.

Also, the serviceability of animal guards should be checked periodically and appropriate action taken to insure their efficiency.

Deflection monitoring. After the initial deflection check (see CONSTRUCTION/INSTALLATION GUIDELINES), subsequent checks should be made at approximately 5-year intervals, or immediately after any landslides, earthquakes, adjacent excavation, major construction work over the pipeline, or any other event that may cause excessive deflections. These checks and the monitoring of deflections will form a basis for maintenance involving major repair or replacement within the pipe system.

Repair. PVC and ABS plastic pipe are easy to cut using hand or power saws. Replacement of sections can be performed using available sleeves. Gasketed sleeves should be used whenever possible, except for

slip-fit underdrains. Corrugated PE tubing is easily cut with snips or saws. Mating connections can be made with standard fittings.

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APPENDIX A

Applicable ASTM Standards

1.	D 543-67	Standard Method of Test for Resistance of Plastics to Chemical Reagents (1972)
2.	D 621-64	Standard Methods of Test for Deformation of Plastics Under Load
3.	D 638-72	Standard Method of Test for Tensile Properties of Plastics
4.	D 648-72	Standard Method of Test for Deflection Temperature of Plastics Under Flexural Load
5.	D 671-71	Standard Method of Test for Flexural Fatigue of Plastics by Constant-Amplitude-of-Force
6.	D 695-69	Standard Method of Test for Compressive Properties of Rigid Plastics
7.	D 696-70	Standard Method of Test for Coefficient of Linear Thermal Expansion of Plastics
8.	D 746-73	Standard Method of Test for Brittleness Temperature of Plastics and Elastomers by Impact
9.	D 759-66	Standard Recommended Practice for Determining Physical Properties of Plastics at Subnormal and Supernormal Temperatures (1970)
10.	D 790-71	Standard Methods of Test for Flexural Properties of Plastics
11.	D 794-68	Standard Recommended Practice for Determining Permanent Effect of Heat on Plastics (1972)
12.	D 1042-51	Standard Method for Measuring Changes in Linear Dimensions of Plastics (1971)
13.	D 1180-57	Standard Method of Test for Bursting Strength of Round Rigid Plastic Tubing (1972)
14.	D 1242-56	Standard Methods of Test for Resistance to Abrasion of Plastic Materials (1969)
15.	D 1248-74	Standard Specification for Polyethylene Plastics Molding and Extrusion Materials

16.	D 1431-67	Standard Specification for Styrene-Acrylonitrile Copolymer Molding and Extrusion Materials (1974)
17.	D 1435-69	Standard Recommended Practice for Outdoor Weathering of Plastics
18.	D 1527-73a	Standard Specification for Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe, Schedules 40 and 80
19.	D 1598-74	Standard Method of Test for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure
20.	D 1599-74	Standard Method of Test for Short-Time Rupture Strength of Plastic Pipe, Tubing, and Fittings
21.	D 1621-73	Standard Method of Test for Compressive Properties of Rigid Cellular Plastics
22.	D 1623-72	Standard Method of Test for Tensile Properties of Rigid Cellular Plastics
23.	D 1693-70	Standard Method of Test for Environmental Stress-Cracking of Ethylene Plastics (1975)
24.	D 1755-66	Standard Specification for Poly (Vinyl Chloride) Resins (1972)
25.	D 1784-69	Standard Specification for Rigid Poly (Vinyl Chloride) Compounds and Chlorinated Poly (Vinyl Chloride) Compounds
26.	D 1785-74	Standard Specification for Poly (Vinyl Chloride) (PVC) and Chlorinated Poly (Vinyl Chloride) (PVC) Plastic Pipe, Schedules 40, 80, and 120
27.	D 1788-73	Standard Specification for Rigid Acrylonitrile-Butadiene-Styrene (ABS) Plastics
28.	D 1892-68	Standard Specification for Styrene-Butadiene Molding and Extrusion Materials (1974)
29.	D 1939-72	Standard Recommended Practice for Determining Residual Stresses in Extruded or Molded ABS Parts by Immersion in Glacial Acetic Acid
30.	D 2104-74	Standard Specification for Polyethylene (PE) Plastic Pipe, Schedule 40
31.	D 2122-70	Standard Method of Test for Determining Dimensions of Thermoplastic Pipe and Fittings

32. D 2152-67 Standard Method of Test for Quality of Extruded Poly (Vinyl Chloride) Pipe by Acetone Immersion (1972)

33. D 2235-73 Standard Specification for Solvent Cement for Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe and Fittings

34. D 2240-75 Standard Method of Test for Indentation Hardness of Rubber and Plastics by Means of a Durometer

35. D 2287-70 Standard Specification for Nonrigid Vinyl Chloride Polymer and Copolymer Molding and Extrusion Compounds

36. D 2290-69 Standard Method of Test for Apparent Tensile Strength of Ring or Tubular Plastics by Split Disk Method

37. D 2291-67 Standard Recommended Practice for Fabrication of Ring Test Specimens for Reinforced Plastics

38. D 2321-74 Standard Recommended Practice for Underground Installation of Flexible Thermoplastic Sewer Pipe

39. D 2412-68 Standard Method of Test for External Loading Properties of Plastic Pipe by Parallel-Plate Loading (1973)

40. D 2444-70 Standard Method of Test for Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)

41. D 2466-74 Standard Specification for Socket-Type Poly (Vinyl Chloride) (PVC) and Chlorinated Poly (Vinyl Chloride) (CPVC) Plastic Pipe Fittings, Schedule 40

42. D 2467-74 Standard Specification for Socket-Type Poly (Vinyl Chloride) (PVC) and Chlorinated Poly (Vinyl Chloride) (CPVC) Plastic Pipe Fittings, Schedule 80

43. D 2468-73 Standard Specification for Socket-Type Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe Fittings, Schedule 40

44. D 2469-73 Standard Specification for Socket-Type Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe Fittings, Schedule 80

45.	D 2474-69	Standard Specification for Vinyl Chloride Copolymer Resins
46.	D 2552-69	Standard Method of Test for Environmental Stress Rupture of Type III Polyethylenes Under Constant Tensile Load (1974)
47.	D 2564-73a	Standard Specification for Solvent Cements for Poly (Vinyl Chloride) (PVC) Plastic Pipe and Fittings
48.	D 2583-75	Standard Method of Test for Indentation Hardness of Plastics by Means of a Barcol Impressor (1972)
49.	D 2586-68	Standard Method of Test for Hydrostatic Compressive Strength of Glass-Reinforced Plastic Cylinders (1974)
50.	D 2609-74	Standard Specification for Plastic Insert Fittings for Polyethylene (PE) Plastic Pipe
51.	D 2610-73	Standard Specification for Butt Fusion Polyethylene (PE) Plastic Pipe Fittings, Schedule 40
52.	D 2611-73	Standard Specification for Butt Fusion Polyethylene (PE) Plastic Pipe Fittings, Schedule 80
53.	D 2648-70	Standard Recommended Practice for Measuring Time-to-Failure by Rupture of Plastics Under Tension in Various Environments
54.	D 2657-67	Standard Recommended Practice for Heat Joining of Thermoplastic Pipe and Fittings (1972)
55.	D 2661-74a	Standard Specification for Acrylonitrile-Butadiene-Styrene (ABS) Plastic Drain, Waste, and Vent Pipe and Fittings
56.	D 2665-74	Standard Specification for Poly (Vinyl Chloride) (PVC) Plastic Drain, Waste, and Vent Pipe and Fittings
57.	D 2672-73	Standard Specification for Bell-End Poly (Vinyl Chloride) (PVC) Pipe
58.	D 2680-74	Standard Specification for Acrylonitrile-Butadiene-Styrene (ABS) Composite Sewer Piping
59.	D 2729-75	Standard Specification for Poly (Vinyl Chloride) (PVC) Sewer Pipe and Fittings

60.	D 2737-74	Standard Specification for Polyethylene (PE) Plastic Tubing
61.	D 2740-74	Standard Specification for Poly (Vinyl Chloride) (PVC) and Chlorinated Poly (Vinyl Chloride) (CPVC) Plastic Tubing
62.	D 2749-68	Standard Symbols for Dimensions of Plastic Pipe Fittings (1973)
63.	D 2750-72	Standard Specification for Acrylonitrile-Butadiene-Styrene (ABS) Plastic Utilities Conduit and Fittings
64.	D 2751-75	Standard Specification for Acrylonitrile-Butadiene-Styrene (ABS) Sewer Pipe and Fittings
65.	D 2836-72	Standard Specification for Filled Poly (Vinyl Chloride) (PVC) Sewer Pipe
66.	D 2837-69	Standard Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials
67.	D 2842-69	Standard Method of Test for Water Absorption of Rigid Cellular Plastics (1975)
68.	D 2852-74	Standard Specification for Styrene-Rubber Plastic Drain Pipe and Fittings
69.	D 2855-73	Standard Recommended Practice for Making Solvent-Cemented Joints with Poly (Vinyl Chloride) (PVC) Pipe and Fittings
70.	D 2924-70	Standard Method of Test for External Pressure Resistance of Plastic Pipe
71.	D 2949-71	Standard Specification for 3-in. Thin Wall Poly (Vinyl Chloride) (PVC) Plastic Drain, Waste, and Vent Pipe and Fittings
72.	D 2951-71	Standard Method of Test for Thermal Stress Crack Resistance of Types III and IV Polyethylene Plastics
73.	D 2952-71	Standard Specification for Ethylene Plastics
74.	D 2990-75	Standard Method of Test for Tensile Creep and Creep Rupture of Plastics
75.	D 2991-71	Standard Recommended Practice for Testing Stress-Relaxation of Plastics

76.	D 3011-74	Standard Specification for Reinforced and Filled Polystyrene, Styrene-Acrylonitrile, and Acrylonitrile-Butadiene-Styrene for Molding and Extrusion
77.	D 3033-75	Standard Specification for Type PSP Poly (Vinyl Chloride) (PVC) Sewer Pipe and Fittings
78.	D 3034-74	Standard Specification for Type PSM Poly (Vinyl Chloride) (PVC) Sewer Pipe and Fittings
79.	D 3036-73	Standard Specification for Poly (Vinyl Chloride) (PVC) Plastic Line Couplings, Socket-Type
80.	D 3039-74	Standard Method of Test for Tensile Properties of Oriented Fiber Composites
81.	D 3045-74	Standard Recommended Practice for Heat Aging of Plastics Without Load
82.	D 3122-72	Standard Specification for Solvent Cements for Styrene-Rubber (SR) Plastic Pipe and Fittings
83.	D 3138-72	Standard Specification for Solvent Cements for Joining Acrylonitrile-Butadiene-Styrene (ABS) Pipe and Fittings to Poly (Vinyl Chloride) (PVC) Pipe and Fittings for Non-Pressure Applications
84.	D 3171-73	Standard Method of Test for Fiber Content of Reinforced Resin Composites
85.	D 3212-73T	Tentative Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals
86.	D 3261-73	Standard Specification for Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing
87.	D 3262-73	Standard Specification for Reinforced Plastic Mortar Sewer Pipe
88.	D 3298-74	Standard Specification for Styrene-Rubber (SR) Plastic Drain Pipe, Perforated
89.	D 3311-74	Standard Specification for Drain, Waste, and Vent (DWV) Plastic Fittings Patterns
90.	D 3350-74	Standard Specifications for Polyethylene Plastics Pipe and Fittings Materials

91. D 3355-74 Standard Method of Test for Fiber Content of Unidirectional Fiber/Polymer Composites

92. F 402-74 Standard Recommended Practice for Safe Handling of Solvent Cements Used for Joining Thermoplastic Pipe and Fittings

93. F 405-74 Standard Specification for Corrugated Polyethylene Tubing

94. F 409-75 Standard Specification for Acrylonitrile-Butadiene-Styrene (ABS) and Poly (Vinyl Chloride) (PVC) Plastic Tube and Tubular Fittings

95. F 412-75 Standard Definitions of Terms Relating to Plastic Piping Systems

96. F 438-76 Standard Specification for Socket-Type Chlorinated Poly (Vinyl Chloride) (CPVC) Plastic Pipe Fittings, Schedule 40

97. F 439-76 Standard Specification for Socket-Type Chlorinated Poly (Vinyl Chloride) (CPVC) Plastic Pipe Fittings, Schedule 80

98. G 21-70 Standard Recommended Practice for Determining Resistance of Synthetic Polymeric Materials to Fungi (1975)

99. G 22-67T Tentative Recommended Practice for Determining Resistance of Plastics to Bacteria

APPENDIX B

Trip Reports

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
VICKSBURG, MISSISSIPPI 39180

IN REPLY REFER TO: WESSE

21 July 1976

MEMORANDUM FOR RECORD

SUBJECT: Inspection of Plastic Pipe Installations and Data/Information Gathering Trip, 8-11 June 1976

1. On 8-9 June 1976 I visited the city offices of the City of Deephaven, MN, for the subject purposes. Deephaven installed approximately 100,000 ft (33,000 m) of Acrylonitrile-Butadiene-Styrene (ABS) Composite sewer pipe in early 1971. Thus the plastic sewer pipe has been in service for a little over 5 years. On 9-10 June I visited the City of Colorado Springs, CO, for the same purposes. Colorado Springs has over 150 miles of ABS Composite sewer pipe installed and is currently installing more. The initial installation was in 1969; therefore, this pipe has seen approximately 7 years of service. On 10-11 June, I was in Denver where I was able to contact and consult with a WES consultant from Utah State University who was in Denver for another purpose. Then I visited the Bureau of Reclamation (BuRec) Office in the Denver Federal Center to discuss their testing/experience with plastic pipe and to obtain any recently published material they might have.

Deephaven

2. My initial contact in Minnesota was Mr. Charles W. Britzius, a former Mayor of Deephaven (he was Mayor at the time of installation of the ABS sewer). Mr. Britzius is a principal engineer of a soils and materials consulting firm in the Minneapolis area. He referred me to the other people contacted: Mr. Walter Sargent of Schoell & Madson, Inc., Consulting Engineers, Hopkins, MN; and Mr. Wallace (Walley) Roholt, Building Inspector and Utility Superintendent for the City of Deephaven.

3. The Deephaven installation of ABS Composite pipe (ARMCO Truss Pipe) has performed well in service. Messrs. Sargent and Roholt are

in complete agreement that there have been very few problems of any kind, and these have been minor. Only one incident that could be classed as a fault of the pipe was recounted to me. At one location, a leak was discovered in the force main in the fall of 1975. When it was uncovered, the pipe was observed to have a hole about the size of a pencil through the wall. It was postulated that there was a manufacturing defect in that particular joint of pipe at the time of construction in the form of a pin-hole. It was probably so small when air-tested (or it was plugged by some very fine-grained soil particles) that no leak was detected at that time. During some 4 years of service the small hole was either enlarged gradually purely by scouring of water under hydraulic pressure or the "plug" was forced out and scouring was allowed to occur. The leak became noticeable only after the hole approached the diameter of a pencil. The total cost of repair was less than $100.

4. Some polyvinyl chloride (PVC) sewer pipe has also been installed in Deephaven. As with the ABS pipe, no major problems have arisen. The individual residence or business service lines are usually PVC, and the only identified potential problem has been at the clean-outs to these services. If the clean-out pipe is allowed to breach the surface, the extreme winter cold of Minnesota makes the pipe brittle to the point that it can be broken easily. However, in the instances when breakage has occurred, it probably would not have mattered whether the pipe was brittle or not because it was broken off by construction equipment such as dozers running over the pipe.

5. Inclosure 1 is a copy of the applicable division (with changes) of the construction specifications for the project that included the installation of the sanitary sewer and force mains. Inclosure 2 is a schematic set of cross sections showing the bedding and backfill details. This inclosure is a facsimile of one of the specification/as-built drawings.

6. The minimum cover depth in Minnesota is the depth of frost penetration, which varies between 4 and 7 ft. The maximum depth of plastic pipe installation in Deephaven is about 28 ft.

Colorado Springs

7. In Colorado Springs, Messrs. Wes Fielder and Harry Huggins, Collection System Superintendent and Pipeline Inspector Supervisor, respectively, of the City of Colorado Springs were my contacts.

8. The great majority of plastic pipe installed in the sewer system of Colorado Springs has also been ABS Composite pipe. All installations of plastic pipe have performed virtually maintenance-free, with no significant repairs necessary. Routine maintenance consisting of water jetting and/or saw-cleaning at appropriate times has been performed. The former procedure (used until last year) was to "rod" or "saw" after the pipe had been in service about 5 years. Mr. Fielder has instituted a new policy whereby the pipe is water-jetted about once each year. He has found that this prevents buildup of sludge or clogging materials and makes potentially damaging "rodding" or "sawing" unnecessary.

9. PVC pipe is also used in Colorado Springs mainly for individual residence or small business service lines. PVC pipe, 8 to 15 in. in diameter, must have a maximum standard dimension ratio (SDR) or 35 and conform to ASTM D3034.

10. The ABS pipe used in Colorado Springs is of two types, depending on size groups. Solid wall pipe, 6 in. or less in diameter, must conform to ASTM D2751, with a maximum SDR of 23.5. ABS Composite pipe from 8 to 15 in. in diameter must conform to ASTM D2680. Inclosures 3 and 4 are specification drawings presently being used in Colorado Springs showing cross sections, including bedding and backfill details and manhole construction details.

11. The maximum installation depth in Colorado Springs is 24 ft. This geologic region is a good area from which to draw performance data and conclusions concerning or relating to the type of soil in which the plastic pipe is installed. In a relatively small area in and around Colorado Springs there exists a wide range of types of soil and/or rock. Soils vary quite widely from low pH (acidic) to high pH (alkaline); from fine texture to coarse texture; from clayey to gravelly; and from residual to transported (aeolian, alluvial, and colluvial). Rock materials are various forms of Igneous, Sedimentary, and Metamorphic rock.

12. Joints have been of the solvent type until quite recently. However, ARMCO (the manufacturer of virtually all of the ABS pipe used in Colorado Springs) is now changing to the O-ring joint.

13. Inclosure 5 is a report on some deflectometer tests that were performed in 1972.

14. One particular construction practice that has been (and is being) used in Colorado Springs for installation of the sewer pipe is highly recommended by Messrs. Fielder and Huggins for use almost universally. That is the use of lasers to set and control line and grade of the pipe. Lasers are beginning to be widely used, but these men made special mention of their satisfaction with and recommendation of this construction practice.

Denver

15. While in Denver, I made two contacts. First, I consulted Dr. R. K. Watkins, a WES consultant from Utah State University. Then I visited Messrs. A. K. Howard and Henry Johns of the BuRec at the Denver Federal Center.

16. Professor Watkins and his associates have conducted extensive research concerning plastic pipe. We discussed various tests and requirements. He outlined several research projects that he has been involved in over recent years and told about some present work he is doing with the use of vacuum for testing. He will furnish me with a copy of a crude report that has been written but not finalized. He recommends that the test for ring stiffness of plastic pipe (elastomeric) use a 15-deg "V" block. In essence, this is a variable three-edge bearing test. For calculation of the ring stiffness, the term D^3/EI (or r^3/EI) is more applicable to pipe to be subjected to variable pressures such as would occur due to live loads over minimum cover (this is opposed to using D^2/EI for concentrated line loads). Professor Watkins recounted an actual case from his experience that showed that 1.75 percent deflection caused strain-corrosion of the top of Reinforced Plastic Mortar (RPM) sanitary sewer pipe (however, this could have been due to bad construction rather than a property of the particular pipe material). A follow-up visit will be made to Utah State University sometime in late July in order to observe some actual testing, the facilities being used, and to get the up-to-date information resulting from the research project presently being conducted there.

17. Mr. Amster Howard of the BuRec has conducted much testing of various types of plastic piping and materials; largely concentrating on the effects of the soils and bedding materials in which the pipe is installed. A majority of the "box testing" he has performed using the huge 5,000,000-lb testing machine has been with RPM pipe. Some

work has been done on PVC and an even smaller amount on corrugated polyethylene (PE) pipe. A November 1975 report by Mr. Howard contains much useful information. One factor of interest is that BuRec testing indicates a practical limit of 50 ft on fill depth, or depth of cover, over virtually all types of plastic pipe. In our discussion Mr. Howard indicated that in his opinion ring stiffness testing should not be a requirement except for RPM piping. I presently have copies of several of Mr. Howard's reports, and will make maximum use of them.

18. Mr. Henry Johns, materials engineer, BuRec, has run many tests of varying kinds on virtually all types of plastic pipe that are designed for use as underdrains. PE, PVC, and ABS are the most common materials used for underdrains. The single least standardized factor among the various commercial offerings of plastic underdrain pipe is the configuration of the perforations. Some are sawed slots, some are punched round holes, some are drilled holes, some are cut slots, etc. Sizes, spacing, and location relative to corrugations are also nonstandardized. Mr. Johns furnished me with two sets of specifications for PE drainage tubing that are presently used by BuRec.

Future plans

19. Present plans are to make another trip in mid-July. The proposed itinerary will be: Washington, DC (OCE); Simpson, Gumpertz, and Heger, Inc., Cambridge, MA; Minot AFB, ND; and Utah State University (Professor R. K. Watkins), Logan, UT. At OCE I will talk with Messrs. Don Knudsen and Paul Carmichael, and in Massachusetts, I will visit with Dr. Frank Heger and Mr. Richard Chambers. Minot AFB is the only place known to me to have installed plastic pipe in the airfield drainage system.

Gary G. Harvey

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GARY G. HARVEY
Engineer
Soil Mechanics Division
Soils and Pavements Laboratory

CF w/o incl:
H. Ulery

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
VICKSBURG, MISSISSIPPI 39180

IN REPLY REFER TO: WESSE

27 August 1976

MEMORANDUM FOR RECORD

SUBJECT: Data/Information Gathering and Inspection of Plastic Pipe Installations Trip, 25-31 July 1976

1. On 25-26 July 1976, I visited in the Office, Chief of Engineers (OCE), Washington, D. C. The purposes of the visit were to discuss the Corps of Engineers (CE) position, policies, recommendations, etc., concerning the use of plastic pipe in storm (gravity) sewers, collector drains, and subdrains, and to collect copies of existing publications (Guide Specifications, Engineer Technical Letters (ETL), etc.) on the subject. On 26-28 July, I visited the consulting engineer firm of Simpson, Gumpertz, and Heger, Inc.(SG&H), Cambridge, Massachusetts, to discuss their on-going project under contract with the Federal Highway Administration (FHWA) and sponsored as Project 4-11 of the National Cooperative Highway Research Program (NCHRP). Next I visited Minot Air Force Base (AFB), Minot, North Dakota, on 28-29 July, to inspect some plastic pipe installations and to gather design, construction, and performance information. Minot Air Force Base is the only place known to me to have installed plastic pipe in the airfield drainage system; and because my project for the Federal Aviation Administration (FAA) concerns use of plastic pipe in airport drainage systems, I believed it appropriate to obtain as much information as possible from Minot. Finally, on 29-31 July, I visited with our (WES) consultant concerning pipe for drainage systems at Utah State University, Logan, Utah.

Washington, D. C.

2. My primary contact at OCE was Mr. Donald Knudsen, DAEN-MCE-U. Our discussion was quite informative, and Mr. Knudsen furnished me copies of two relatively recent ETL's and some applicable guide specifications. The ETL's are: ETL 1110-1-82, 28 November 1975, "Water Supply-Water Distribution Systems" and ETL 1110-1-84, 2 February 1976, "Sanitary Sewers." These ETL's were written specifically to allow the use by CE units of plastic piping materials in the two types of subject systems. I also consulted briefly with Mr. Sam Gillespie, DAEN-MCE-D. He has recently published a revised guide specification for "Subdrainage Systems." The new identification number is Federal Construction Guide Specification (FCGS) 02502,

August 1976. I also received copies of several other recently revised and updated guide specifications which have included plastic pipe in many of the sewer and drainage systems in use by the various Federal agencies.

Cambridge, Mass.

3. Mr. Richard (Dick) Chambers was my host at SG&H, but I also talked with Dr. Frank Heger. Along with the several hours of fruitful discussion, I was privileged to visit one of the SG&H test sites. The site is located a few miles inside New Hampshire from Boston on I-95. I accompanied Mr. Steve Condren of SG&H to the site where there are actually two different test installations of plastic pipe.

a. The first, called NH-1, is a 200-ft culvert-type installation of polyvinyl chloride (PVC) sewer pipe of two different Standard Dimension Ratios (SDR). Half of the length is SDR 35 and half is SDR 41. The pipe was buried 5 ft below the surface of an I-95 temporary bypass, and the embedment material was of three classes: I, II, and III. The pipe was installed on 22-23 September 1975 by the I-95 contractor. Each type of pipe was instrumented with a set of eight strain gages to measure crown, invert, and springline strains. Although the culvert has silted full since installation, deflection measurements were made while the pipe was still open. No attempt has been made to monitor the traffic that has passed over the temporary bypass. Many of the strain gages became inoperative by December of 1975, probably due to insufficient gage waterproofing. The pipe will be dug up in 1977, and examined and tested in various ways at that time.

b. NH-2 (and NH-2.1) is also an installation of plastic pipe in the culvert mode, but none of the individual pipes actually carry waterflow. There are three 140-ft pipes, but two of these are composed of two 70-ft lengths of two different pipe types and/or dimensions. One culvert installation is 70 ft of 12-in.-diam PVC sewer pipe, ASTM D3033, SDR 41; and 70 ft of 12-in.-diam PVC sewer pipe, ASTM D3034, SDR 35. A second installation is half 8-in.-diam corrugated perforated polyethylene (PE) tubing, conforming to ASTM F405-Hvy Dty; and half 16-in.-diam solid wall PE sewer pipe for which there is no ASTM standard or specification. The third pipe is 140 ft (continuous) of 15-in-diam acrylonitrile-butadiene-styrene (ABS) composite pipe. ABS composite pipe is double-walled, with the space between the walls filled with a stiff ABS plastic truss and an insulating foamed-in mortar. The envelope material for all three of these pipe lengths was Class III. Both grooved and flat bedding were used. The pipe was installed in early November 1975 under the end of an approach embankment to a bridge abutment for a road that crosses I-95. Initial cover depth was 2 ft 6 in., and the site was used as a construction haul

road at that depth. Then the embankment was built to a height such that the cover was approximately 20 ft. Deflection measurements were taken at several phases during the installation and construction; however, these initial measurements were suspect because of an apparent malfunction in the measuring device. The center 20 ft of each of these three culvert installations were dug up and removed for testing and evaluation in April 1976. The PVC pipe sections cut out were replaced with instrumented sections of the same type of pipe (designated NH-2.1 by SG&H). At the time that the pipe sections were removed, the embankment was removed down to a pipe cover depth of 3.5 ft for the bridge abutment construction. At the time of this visit the cover depth was still 3.5 ft, but the contractor was expected to begin reconstruction of the embankment in the near future. The final cover over the pipe lines will be about 22 ft. The pipe installation will remain as a permanent test site. An unmonitored, yet significant, amount of heavy construction traffic has been applied at the 3.5-ft cover depth. The instrumentation consists of three circumferential rings of strain gages with 12 gages in each ring. At least three of the gages are no longer operable, but data received from the others are consistent and reasonable. SG&H has not begun to analyze these data yet. Mr. Chambers is chairman of one ASTM subcommittee concerned with plastic pipe and is an active member of several others. He provided copies of several proposed new ASTM standards and modifications of existing ones for my use. He asked me to forward to him for his consideration any comments that I may wish to make on them. SG&H is very interested in any future testing program concerning repetitive loadings on buried plastic pipe.

Minot AFB, North Dakota

4. My initial contact upon arrival at Minot AFB was Mr. James Morley of the Construction Branch of the Base Civil Engineer's Office (BCE). Mr. Morley is a former CE employee (he was Area Engineer until the area office was closed in 1975) who was the Contracting Officer's Representative on the construction project that placed some plastic subdrain pipe adjacent to an airfield alert taxiway and its satellite parking apron. Unfortunately, many of the construction records which would have been most helpful were unavailable because they were sent to the Omaha District Office after completion of construction. However, Mr. Morley was able to tell me enough from his experience and observations to make the visit worthwhile. Mr. Ken Johnson, also of BCE (Utilities), furnished some useful information; although it was mostly concerning plastic pipe used for pressure gas lines at Minot AFB. Experience with plastic pipe of various materials used in various ways is fairly broad at Minot. DuPont PE "Aldyl-A" pipe has been used for pressure gas lines; Certainteed PVC "Yelogas" pipe was used for parts of the gas system prior to 1973 when its use was discontinued because of excessive brittleness after installation; Certainteed PVC pipe conforming to ASTM 3034, SDR 35, has

been used satisfactorily for gravity sewers on the base; Yardley ABS pipe (ASTM D2661) has been used for drain, waste, and vent (DWV) pipe; and Johns-Manville (JM) PVC "Ring-Tite" pipe conforming to ASTM D2241 with three different SDR values depending on design internal pressure has been used in gas and water distribution systems. The rather thick-walled (SDR ≈ 7) DuPont PE pipe has been and is being used more than any of the others in pressure applications. Although none of the perforated PVC underdrain pipe along the airfield taxiway and parking apron has been dug up or inspected, base personnel believe it is still performing well after more than three years of service. Mr. Morley furnished a copy of the applicable sections of the contract specifications for that project.

Logan, Utah

5. At Utah State University I met with Dr. Reynold K. Watkins, who is a WES consultant. We discussed several new developments that had occurred since our meeting in Denver in June (reference MFR dated 21 July 1976; subject: Inspection of Plastic Pipe Installations and Data/Information Gathering Trip, 8-11 June 1976). Dr. Watkins furnished copies of several research reports and technical papers which should be of great value for use in the project's Phase II Interim Report (due by 30 September 1976). The Utah State Engineering Experiment Station is well equipped and adequately staffed and administered to perform testing of various types and sizes of pipe for a continuation of Phase II of this subject project or for future directly or indirectly related research. Testing facilities include a 1,000,000-lb loading device, a smaller 150,000-lb device, and limited facility for traffic testing; i.e., truck loads applied at slow speed. Professor Watkins is an accomplished scientist and innovator in the use of model-prototype similitude. Much important information has been obtained through his model studies.

6. No more travel will be necessary prior to completion of this part of Phase II of the plastic pipe project.

Gary D. Harvey
GARY HARVEY
Engineer
Soil Mechanics Division
Soils and Pavements Laboratory

CF:
Harry Ulery